DRAFT

ENDOSULFAN

RISK CHARACTERIZATION DOCUMENT

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Exposure Assessment

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ESTIMATION OF EXPOSURE OF PERSONS IN CALIFORNIA TO PESTICIDE PRODUCTS THAT CONTAIN ENDOSULFAN

HS-1647

By

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ABBREVIATIONS AND ACRONYMS

ADD	absorbed daily dosage
AADD	annual average daily dosage
AI	active ingredient
ARB	California Air Resources Board
CAS No.	Chemical Abstracts Service Number
CCR	California Code of Regulations
CFAC	California Food and Agriculture Code
CFR	Code of Federal Regulations
CFWAP	California Farm Worker Activity Profile
DFR	dislodgeable foliar residue
DPR	California Department of Pesticide Regulation
EAD	exposure assessment document
EC	emulsifiable concentrate
FR	Federal Register
GABA	gamma-amino butyric acid
LADD	lifetime average daily dosage
LOD	limit of detection
LOQ	limit of quantification
M/L	mixer/loader
M/L/A	mixer/loader/applicator
PCO	pest control operator
PHED	Pesticide Handler Exposure Database
PHI	pre-harvest interval
PISP	Pesticide Illness Surveillance Program
PPE	personal protective equipment
PUR	Pesticide Use Report
RED	Reregistration Eligibility Decision
REI	restricted entry interval
SADD	seasonal average daily dosage
STADD	short-term absorbed daily dosage
TAC	toxic air contaminant
TC	transfer coefficient
TWA	time-weighted average
UCL	upper confidence limit
U.S. EPA	U.S. Environmental Protection Agency
WHS	Worker Health and Safety Branch
WP	wettable powder
WSP	water-soluble packaging

ABSTRACT

The purpose of this document is to summarize available information, data and calculations of exposures related to uses of endosulfan in California. Exposure estimates and scenarios are used in the endosulfan risk characterization document prepared by the California Department of Pesticide Regulation (DPR). Endosulfan is a foliar insecticide used to control insect pests in a variety of crops. A human exposure assessment for this insecticide was prompted by the observation of acute effects in a 21-day rat dermal toxicity study. The metabolism and pharmacokinetic information on this insecticide indicates that it is relatively quickly eliminated after oral administration. Metabolites consist of a sulfate and a diol; the diol is oxidized further to species that undergo cyclization. Metabolism to the sulfate is catalyzed by cytochrome P-450 enzymes. Two endosulfan formulations are registered in California, an emulsifiable concentrate (EC) containing 34% active ingredient (AI), and a wettable powder (WP) containing 50% AI. Both formulations are registered for use on several crops. Endosulfan may be applied by aerial or ground methods; application by any irrigation method is prohibited in California.

Exposure scenarios were identified based on uses listed on product labels. No acceptable chemical-specific exposure data were available. Handler exposures were estimated using surrogate data from the Pesticide Handler Exposure Database; separate dermal and inhalation exposures are provided as well as combined total exposure estimates. Combined short-term absorbed daily dosage (STADD) estimates for mixer/loaders (M/Ls) range from 0.00003 to 5.40 mg/kg/day (for M/Ls handling EC products in support of nursery stock dipping and M/Ls handling WP products in support of high-acre aerial applications, respectively). Applicator STADD estimates range from 0.045 to 41.4 mg/kg/day (groundboom and nursery stock dipping applications, respectively). The STADD estimate for flaggers is 0.373 mg/kg/day. The STADD estimates for mixer/loader/applicators (M/L/As) range from 0.010 to 0.511 mg/kg/day (for M/L/As using low pressure handwand and high pressure handwand, respectively). Seasonal average daily dosage (seasonal ADD) estimates for handlers range 0.003 – 1.32 mg/kg/day. Annual ADD estimates range 0.0005 – 0.330 mg/kg/day. Lifetime ADD estimates range 0.0003 – 0.176 mg/kg/day.

Reentry exposures were estimated using dislodgeable foliar residue data for endosulfan applied to four crops (grape, melon, peach, and lettuce) and transfer coefficients from several studies using surrogate chemicals. STADD estimates range from 0.009 mg/kg/day for workers hand harvesting ornamental plants to 0.533 mg/kg/day for workers hand harvesting sweet corn. Seasonal ADD estimates range 0.004 – 0.141 mg/kg/day. Annual ADD estimates range 0.001 – 0.047 mg/kg/day. Lifetime ADD estimates range 0.0007 – 0.025 mg/kg/day.

Public exposures to airborne endosulfan were also estimated. Bystander exposure estimates, for individuals who are next to fields during or following endosulfan applications, were based on air monitoring done 6 – 16 m from the edge of an apple orchard during an application. STADD estimates for bystanders are 0.00160 mg/kg/day

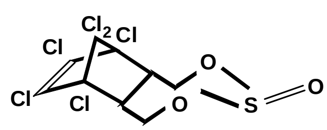
for infants and 0.00076 mg/kg/day for adults. Seasonal ADD estimates for bystander exposures to endosulfan are 0.00056 mg/kg/day for infants and 0.00027 mg/kg/day for adults. Annual ADD estimates for bystanders are 0.000047 mg/kg/day for infants and 0.000022 mg/kg/day for adults.

Exposure estimates for swimmers were based on endosulfan concentrations reported to DPR from numerous environmental monitoring studies. STADD for children and adults swimming in California surface waters containing endosulfan are 0.00156 and 0.00027 mg/kg/day, respectively.

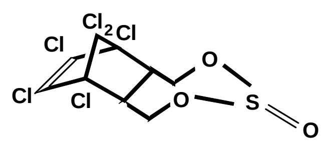
INTRODUCTION

Endosulfan is a cyclodiene chlorinated hydrocarbon that was first registered as a pesticide in the United States in 1954. The chemical name of endosulfan is *6,7,8,9,10,10*-hexachloro-*1,5,5a,6,9,9a*-hexahydro-*6,9*-methano-*2,4,3*-benzodioxathiepin 3-oxide. Its molecular weight is 406.96; its formula is $C_9H_6Cl_6O_3S$; and its Chemical Abstracts Service Number (CAS No.) is 115-29-7. Endosulfan is a broad-spectrum foliar insecticide and miticide that is used on more than 50 crops in California.

Endosulfan is a colorless, crystalline solid that exists in two isomers, α and β; these isomers are also referred to as endosulfan-1 and endosulfan-2. The α and β isomers constitute 64-67% and 29-32%, respectively, of the technical mixture. The structures of the endosulfan isomers are shown below:



α−Endosulfan



β−Endosulfan

Each isomer has its own CAS No. assigned; these are 959-98-8 and 33213-65-9 for the α and β isomers, respectively.

Some physical properties of endosulfan are listed below (Sarafin, 1979a; Sarafin, 1979b; Sarafin, 1982; Tomlin, 1994):

Melting point α isomer (°C)	109.2
Melting point β isomer (°C)	213.3
Vapor pressure α isomer (mm Hg at 25°C)	1.5×10^{-5}
Vapor pressure β isomer (mm Hg at 25°C)	6.9×10^{-7}
Water solubility α isomer (mg/L at 22°C, pH 5)	0.33
Water solubility β isomer (mg/L at 22°C, pH 5)	0.32
K_{ow} α isomer (at 22°C, pH 5.1)	55,500
K_{ow} β isomer (at 22°C, pH 5.1)	61,400

The log K_{ow} is reported as 4.74 for α-endosulfan and 4.79 for β-endosulfan (Sarafin, 1979b). Sarafin (1982) reported vapor pressure for α-endosulfan and β-endosulfan (listed above), and also for technical endosulfan (purity > 99% for all three test materials) of 1.3

x 10^{-5} mm Hg at 25°C. Because the volatility of α-endosulfan is so much greater than that of β-endosulfan, Sutherland *et al.* (2004) suggested that enriching the commercial formulation with β-endosulfan would result in less volatilization of the pesticide. However, β-endosulfan has been shown to isomerize irreversibly to α-endosulfan (Schmidt *et al.*, 2001). The Henry's Law constant, based on data listed above, is 4.2 x 10^{-5} atm-m^3/mole for α-endosulfan and 2.1 x 10^{-6} atm-m^3/mole for β-endosulfan (calculated by the California Department of Pesticide Regulation (DPR) Environmental Chemistry Branch, internal database). Robinson (1987) reported a Henry's Law constant of 1.01 x 10^{-5} atm-m^3/mole, based on water solubility data collected at 20°C.

Endosulfan is toxic to the central nervous system through generalized brain stimulation. The mode of action of endosulfan is to bind and inhibit γ-amino butyric acid (GABA)-gated chloride channel receptor and thereby inhibiting GABA-induced chloride flux across membranes (Abalis *et al.,* 1986; Ffrench-Constant, 1993; Sutherland *et al*., 2004). The effects on the GABA receptor complex are similar to those of lindane, dieldrin and endrin (Lawrence and Casida, 1984; Casida and Lawrence, 1985; Cole and Casida, 1986). Neurotoxicity has also been attributed to other actions such as an inhibition of the calmodulin dependent Ca^{+2} ATPase activity (Srikanth, *et al*., 1989) and alterations in the serotoninergic system (Agrawal *et al*., 1983).

DPR is charged with protecting individuals and the environment from potential adverse effects that may result from the use of pesticides in the State. This is codified in the California Food and Agriculture Code (CFAC), Sections 11501, 12824, 12825, 12826, 13121-13135, 14102, and 14103. As part of DPR's effort to meet this mandate, pesticide active ingredients (AIs) are prioritized for assessment of exposure and risk potential. A description of the risk prioritization process can be found at DPR's website (http://www.cdpr.ca.gov/docs/risk/raprocess.pdf). When comprehensive risk assessments are initiated for particular AIs, the evaluations are conducted in accordance with California Code of Regulations Title 3, Section 6158 (3 CCR 6158). Pesticide products containing the active ingredient endosulfan are being evaluated on the basis of adverse effects reported in laboratory animal toxicity studies. Reported effects included neurotoxicity, reproductive effects, vascular effects, and effects on kidneys (Silva, 2004). This Exposure Assessment Document (EAD) is the first prepared by DPR for endosulfan.

U.S. EPA STATUS

The U.S. Environmental Protection Agency (U.S. EPA) has assigned endosulfan to Toxicity Category I for oral, Toxicity Category II for inhalation, and Toxicity Category III for dermal exposure (U.S. EPA, 2002a). U.S. EPA (2002a) considers endosulfan to be an eye irritant (Toxicity Category I), but not a dermal irritant or sensitizer.

A Reregistration Eligibility Decision (RED) for endosulfan was issued by U.S. EPA in 2002. In the absence of sufficient data suggesting otherwise, the RED assumed that endosulfan did not share a common mechanism of toxicity with any other AI. The RED stated several human health and ecological risk concerns, including both handler and reentry occupational exposures, and suggested measures to mitigate each (U.S. EPA, 2002a). These measures, and the predicted effects on exposure estimates, are discussed in this EAD. Exposure estimates were not given in the RED; a document released previously presented exposure calculations (U.S. EPA, 2002b). Information and conclusions from U.S. EPA (2002a; 2002b) were considered by DPR during the preparation of this EAD. However, exposure scenarios considered by DPR differed somewhat from those considered by U.S. EPA. Additionally, several assumptions used in exposure assessments differed between DPR and U.S. EPA. Such differences are discussed in this EAD when appropriate.

FORMULATIONS AND USES

As of November 2007, two formulations were registered in California, an emulsifiable concentrate (EC) containing 34% AI (sold in two products), and a wettable powder (WP) containing 50% AI (sold in three products). In addition to these five products, a 95% AI technical endosulfan is registered solely for manufacturing use. The EC formulation contains 3 lbs AI/gallon (0.36 kg AI/L). Both EC and WP formulations are registered for use on several crops, all of which are listed in Appendix 1. Endosulfan may be applied by aerial or ground methods; application by any irrigation method is prohibited in California.

A proposed new product has been submitted for registration in California, an ear tag consisting of impregnated material containing 30% endosulfan. This product is proposed for use on cattle, to protect against the hornfly. Information is still being obtained for this product, and it is not considered further in this EAD.

PESTICIDE USE AND SALES

California requires reporting of all agricultural uses of pesticides, as well as other uses when pesticides are applied by a licensed applicator. These data are collected in the Pesticide Use Report (PUR) database. Table 1 summarizes PUR data for the crops on which most endosulfan use occurred during the five-year interval 2001 – 2005. The greatest use was in tomato, lettuce, alfalfa, and cotton; together these crops accounted for about 78% of endosulfan use in 2005. In 2005, there were 194,310,983 pounds of pesticide active ingredients reported used in California (DPR, 2006c). Overall, of the pesticide use reported to DPR in 2005, endosulfan accounted for 83,185 lbs, or 0.043%.

Although use on individual crops can fluctuate, total use of endosulfan was relatively stable between 2001 and 2004. Use dropped sharply in 2005, mostly due to decreased use on cotton; this correlates to fewer acres of cotton having been planted (DPR, 2006c). Endosulfan is used on cotton mainly to control whitefly and aphid populations. These insects produce sugary excretions, fouling cotton lint in a condition called “sticky cotton.” A major outbreak of these pests triggered increased endosulfan use in 2001, followed by aggressive control in 2002 to prevent a recurrence (DPR, 2003). In contrast, endosulfan use increased on alfalfa between 2004 and 2005. On February 13, 1997, U.S. EPA published a notice in the Federal Register (FR), Volume 62, announcing receipt of requests to delete endosulfan uses on several crops, including alfalfa grown for forage (62

FR 6776-6777). The only remaining use on alfalfa is on alfalfa grown for seed; that use was deleted as of February 2006 (70 FR 48398-48413).

Table 1. Use of Endosulfan by Crop for 2001- 2005

Crop	Pounds Applied [a]				
	2001	2002	2003	2004	2005 [b]
Tomatoes (all types)	21,733	16,143	23,522	20,803	20,275 (24.4)
Lettuce	26,758	22,293	19,549	21,865	18,801 (22.6)
Alfalfa	25,758	10,198	12,334	9,595	13,446 (16.2)
Cotton	44,281	66,837	58,101	76,638	11,952 (14.4)
Cucurbits [c]	16,868	14,295	11,274	12,216	8,829 (10.6)
Beans	876	1,795	512	6	1,426 (1.7)
Peppers	3,248	354	1,248	4,042	1,378 (1.7)
Sweet Corn	428	1,839	319	274	1,297 (1.6)
Crucifers [d]	4,275	3,289	3,847	4,012	891 (1.1)
Potato	686	3,264	470	1,324	776 (0.9)
Tree Nuts [e]	557	250	82	849	648 (0.8)
Stone Fruit [f]	1,691	3,294	495	457	352 (0.4)
Pome Fruit [g]	90	344	591	102	148 (0.2)
Grapes (all types)	4,413	3,160	272	497	143 (0.2)
Sugar Beets	332	2,607	0	252	0 (0.0)
Citrus [h]	0	56	0	0	0 (0.0)
Total of listed crops	151,976	150,018	132,616	152,932	80,362
Total in PUR [i]	153,498	150,954	134,080	153,339	83,185
Listed crops % of total	99.0%	99.4%	98.9%	99.7%	96.6%

[a] Arranged in descending order by use in 2005. Multiply values by 0.455 to get use in kg applied.
[b] Number in parentheses is percent of total endosulfan use in 2004.
[c] Includes cucumbers, melons, pumpkins, squash, summer squash, winter squash and watermelon.
[d] Includes broccoli, Brussels sprouts, cabbage, cauliflower, and Chinese cabbage.
[e] Includes almonds, pecans and walnuts.
[f] Includes apricots, cherries, nectarines, peaches, plums and prunes.
[g] Includes apples and pears.
[h] Includes oranges. No use reported on other citrus fruit.
[i] PUR = Pesticide Use Report (DPR, 2002; 2003; 2005a; 2006b; 2006c).

California collects a fee for all pesticides sold in the state (Mill Assessment sales data). In 2005, a total of 110,704 lbs of endosulfan was sold in California, compared to a total of 611,368,382 lbs of all AIs (DPR, 2007). Thus, endosulfan accounted for about 0.02% of pesticide sales in 2005. For many reasons, the amount of endosulfan (or of any AI) sold in a single year would not be anticipated to equal the amount used. For example, pesticides sold in one year may be used in a different year or over multiple years, or might remain in storage or be discarded. Between 2001 and 2005, annual sales of endosulfan ranged from 110,704 lbs sold in 2005 to 190,654 lbs sold in 2004; an average of 166,160 lbs was sold during the 5-year interval. In contrast, average endosulfan use reported during the interval was 135,011 lbs.

REPORTED ILLNESSES

The purpose of this section is to summarize illness reports for endosulfan. DPR's Worker Health and Safety Branch (WHS) includes a Pesticide Illness Surveillance Program (PISP). PISP maintains a database of all reports of illness and injury potentially related to pesticide exposure in California. The PISP database contains information about the nature of the pesticide exposure and the subsequent illness or injury. DPR uses the database identify high-risk situations and to evaluate the effectiveness of DPR's pesticide safety regulatory programs (WHS, 2007).

PISP defines a "case" as a "person whose health problems may relate to pesticide exposure" (WHS, 2007). PISP scientists evaluate investigations of each case and record a qualitative assessment of the likelihood that pesticide exposure caused or contributed to the reported symptoms. Cases are considered to be associated with exposure to a pesticide as follows: they are evaluated as "definite" (both physical and medical evidence support exposure and consequent health effects), "probable" (incomplete or circumstantial evidence supports a relationship to pesticide exposure) or "possible" (available evidence neither supports nor contradicts a relationship). PISP defines an "episode" as "an event in which a single source appears to have exposed one or more people (cases) to pesticides." Occasionally, a single episode gives rise to a large number of cases.

From 1992 through 2005, PISP identified endosulfan, alone or in combination with other pesticides, as a potential contributor to 58 California illnesses (Mehler, 2007). Agricultural use was the apparent source of the pesticide for all of the illnesses but one (in which the pesticide was used at a golf course). Endosulfan was the only pesticide implicated in the non-agricultural case and in six agricultural episodes that each affected one person.

Of the seven illnesses associated with exposure to endosulfan alone, six were evaluated as possibly related and one as probably related to endosulfan exposure. Two of the seven experienced predominantly irritant symptoms: A greenhouse applicator and a grape harvester developed itchy rashes. The applicator experienced swollen eyes and lips as well. Three people reported both irritant and systemic symptoms: An applicator who splashed endosulfan solution into his face reported numbness in the mouth and nose, pain in the eyes, and itching skin. Another worker developed nausea and weakness as well as itchy and irritated skin after falling into an agricultural drainage canal known to contain a low concentration of endosulfan. A resident who described herself as "very sensitive to chlorinated hydrocarbons" reported itchy skin and eyes, dizziness, and staggering when she smelled an endosulfan application approximately 400 m away. A worker who smelled a nearby aerial application developed a headache and nausea, as did an applicator who used an over-the-vine sprayer to apply endosulfan to grape vines, and who also complained of weakness.

The other 51 agricultural cases occurred in 20 episodes that implicated endosulfan along with one to six additional pesticides, any or all of which may have contributed to adverse effects on health. All but eight of the affected people were agricultural field workers exposed to pesticide residue. Thirty-six of the 43 field workers experienced skin irritation, and 21 of them had no other symptoms. The 43 field workers were exposed in 13 episodes, of which one affected 20 workers and another affected ten. In both of the two large episodes, workers entered fields that they should have been prevented from entering because pesticide applications were too recent. In the episode that affected 20 field workers, the field had been treated with bifenthrin, dicofol, and an adjuvant in addition to endosulfan. In the episode that affected 10 workers, endosulfan had been applied along with esfenvalerate, methomyl, and an adjuvant.

Table 2 summarizes types of symptoms reported in association with endosulfan exposure. The majority of illnesses included skin effects, such as irritation, rashes, redness and blisters.

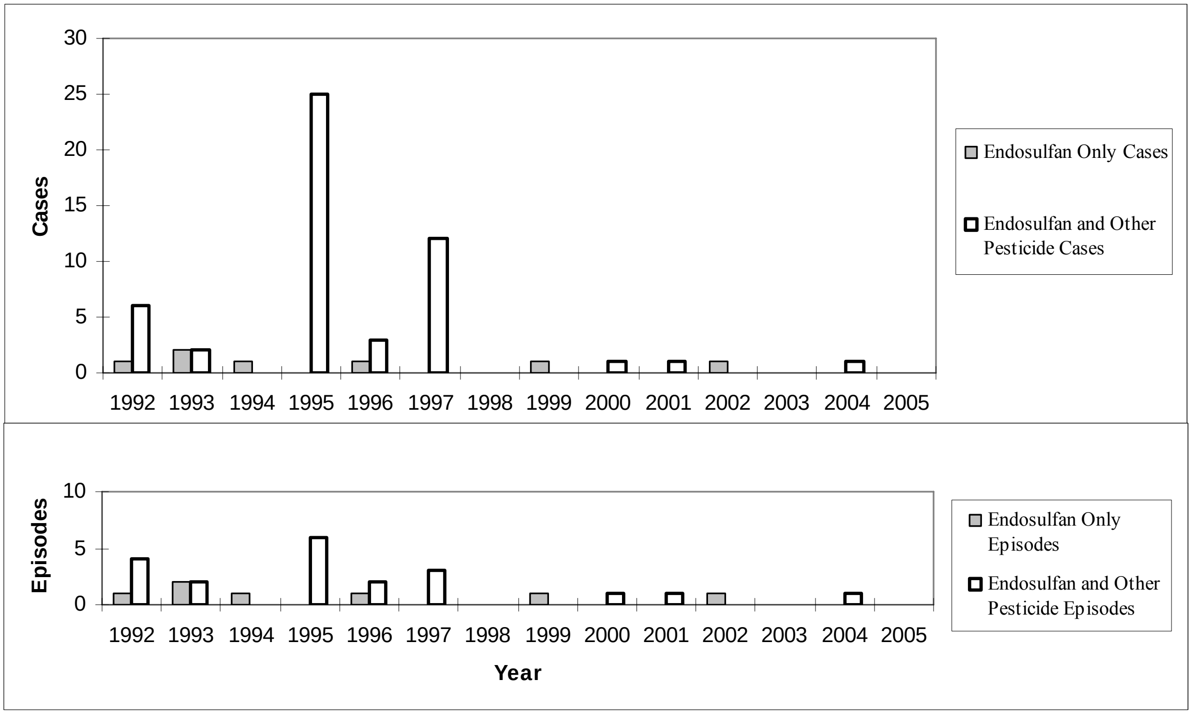
Table 2. Types of Symptoms Reported in Illnesses Evaluated by the California Pesticide Illness Surveillance Program as Definitely, Probably, or Possibly Related [a] to Endosulfan Exposure (1992-2005)

Pesticide Exposure	Types of Symptoms Reported [b]			
	Skin [c]	Eye [d]	Respiratory [e]	Systemic [f]
Endosulfan Alone	5	3	0	4
Endosulfan among Other Pesticides	38	12	15	11
Total	43	15	15	15

[a] "Definite" means that both physical and medical evidence document exposure and consequent health effects, "probable" means that limited or circumstantial evidence supports a relationship to pesticide exposure, and "possible" means that evidence neither supports nor contradicts a relationship (Mehler, 2007).
[b] Twenty-two of the 58 cases reported more than one type of symptom.
[c] Skin effects include irritation, rashes, redness, blisters.
[d] Eye effects include irritation and pain.
[e] Respiratory effects include sore throat, congestion, coughing, wheezing, and shortness of breath.
[f] Systemic illnesses include symptoms such as nausea, dizziness, headache and numbness.

Figure 1 summarizes numbers of endosulfan-associated illnesses and episodes reported annually. The two early-reentry episodes discussed above provided most of the cases shown in Figure 1. A 1995 episode accounted for 20 of 25 cases that year, and another episode accounted for ten of 12 cases in 1997. In each of six years, including 1994, 1999 – 2002, and 2004 only one endosulfan illness was reported. No endosulfan-related illnesses were reported in 1998, 2003, or 2005.

Figure 1. Numbers of Illnesses (Cases) and Episodes Reported in California, 1992 – 2005 and Evaluated by the California Pesticide Illness Surveillance Program as Definitely, Probably, or Possibly Related [a] to Endosulfan Exposure



[a] "Definite" means that both physical and medical evidence document exposure and consequent health effects, "probable" means that limited or circumstantial evidence supports a relationship to pesticide exposure, and "possible" means that evidence neither supports nor contradicts a relationship (Mehler, 2007). More than one case can be associated with each episode.

In the southeastern U.S., two incidents were reported in which mixer/loader/applicators (M/L/As) pouring endosulfan without proper protective equipment experienced serious illnesses (Brandt *et al*., 2001). In both cases, endosulfan splashed onto skin and clothing during mixing and loading; in the second case, drift during the application, enough that his clothes "appeared soaked," was witnessed. Both individuals proceeded with the applications without washing skin or changing the contaminated clothing. Exposure durations were estimated at 4 – 5 hours. Evidence suggested that these exposures resulted in long-term neurological damage in one case, and in death in the other case.

LABEL PRECAUTIONS AND CALIFORNIA REQUIREMENTS

Endosulfan formulations all have the signal word DANGER-POISON on the label. The following is representative of precautionary statements, taken from a WP product (Gowan Endosulfan 50W):

"Fatal if swallowed. May be fatal if inhaled or absorbed through skin. Causes moderate eye irritation. Avoid contact with skin, eyes, or clothing. Do not breathe vapors, dust or spray. Do not apply or allow to drift to areas occupied by unprotected humans or beneficial animals."

"Applicators and other handlers must wear:
- Coveralls over long-sleeved shirt and long pants
- Chemical-resistant footwear plus socks
- Waterproof gloves
- Protective eye wear
- Chemical-resistant head gear for overhead exposure
- Chemical-resistant apron when cleaning equipment, mixing or loading
- A respirator with either an organic vapor-removing cartridge with a prefilter approved for pesticides (MSHA/NIOSH approval number prefix TC-23C), or a canister approved for pesticides (MSHA/NIOSH approval number prefix TC-14G)."

California has an additional requirement for use of protective eyewear during the following activities (exceptions are provided for some of the activities meeting specified criteria): mixing or loading pesticides; cleaning, adjusting, or repairing equipment that contains pesticides in hoppers, tanks or lines; pesticide applications by hand; ground applications of pesticides; and flagging (Title 3 Code of California Regulations (3 CCR), Section 6738). In California, all products containing endosulfan are classified as Restricted Materials (3 CCR 6400), due to toxicity to fish and other aquatic organisms (Rutz, 1997).

California regulations require the use of closed mixing and loading systems for liquid formulations of toxicity category I pesticides and closed loading systems for liquid mixtures of toxicity category I dry formulations (3 CCR 6746). Thus, all formulations of endosulfan require the use of closed systems for loading, and EC formulations also require closed systems during mixing. Many of the WP products are packaged in water-soluble packaging (WSP), which is considered to be a closed system. U.S. EPA proposed requiring all WP endosulfan products to be packaged in WSP to mitigate handler exposure (U.S. EPA, 2002a). As of March 2007, there are still products sold in California that are not in WSP. Therefore, all handlers of liquids were assumed to mix/load using a closed system, and handlers of WP products were assumed to either be handling WSP or to be openly pouring WP.

Handlers mixing/loading using a closed system are allowed by federal and state law to substitute alternate personal protective equipment (PPE) for that listed on product labels. Under the federal Worker Protection Standard (Title 40 Code of Federal Regulations (40 CFR), Section 170.240), "Persons using a closed system to mix or load pesticides with a signal word of DANGER or WARNING may substitute a long-sleeved shirt, long pants, shoes, socks, chemical-resistant apron, and any protective gloves specified on the labeling for handlers for the labeling-specified personal protective equipment." Additionally, "Persons using a closed system that operates under pressure shall wear protective eyewear."

The corresponding California regulations have more restrictive PPE requirements (3 CCR 6738): "Persons using a closed system to handle pesticide products with the signal word 'DANGER' or 'WARNING' may substitute coveralls, chemical resistant gloves, and a chemical resistant apron for personal protective equipment required by pesticide product labeling." Also, "Persons using a closed system that operates under positive pressure shall wear protective eyewear in addition to the personal protective equipment listed...Persons using any closed system shall have all personal protective equipment required by pesticide product labeling immediately available for use in an emergency." The substituted PPE required in California allows workers mixing and loading with a closed system to work without respirators.

According to requirements listed on product labels, the restricted entry interval (REI) is 24 hours for all activities in all crops. The REI is set by California regulations to 2 days for all crops treated with endosulfan (3 CCR 6772). Early reentry into a treated field is permitted only if workers either have no contact with treated foliage, or meet specific requirements of 40 CFR 170.112 and 3 CCR 6770. Pre-harvest intervals (PHIs) for crops treated with endosulfan range from 0 to 21 days (see Appendix 1).

EXPOSURE SCENARIOS

An exposure scenario describes a situation where people may contact pesticides or pesticide residues, and in which the nature of the exposure as well as its magnitude (apart from variability among individuals and occasions) is relatively homogeneous. Only agricultural uses are allowed for endosulfan; therefore, all exposure scenarios take place during or following agricultural applications. Workers can potentially be exposed to endosulfan during handling activities and during reentry into treated fields. In addition, available data suggest that bystander exposures are possible to individuals who are next to fields during or following endosulfan applications, and that airborne endosulfan exposures are possible even in areas that are far from application sites (ambient air exposure). Endosulfan residues have been detected in surface waters in California, suggesting that exposures are possible to individuals swimming in surface waters draining agricultural lands (swimmer exposure).

Handlers

Table 3 lists handling scenarios for endosulfan, based uses listed on product labels. Handler activities include M/L, applicator, M/L/A, and flagger. Flaggers may be used to assist aerial applicators, although use of human flaggers is becoming increasingly rare as newer technologies are adopted. Handlers may be growers or custom applicators; custom applicators may treat crops for many different growers (Haskell, 1998).

For the purposes of this exposure assessment, handler exposures are assumed to be generally independent of crop, and to be dependent upon formulation, application method, and amount handled. Separate M/L exposure scenarios were assessed for each application method and formulation (Table 3). Because the WP formulation is mixed with water and applied as a liquid all applicator exposure estimates assume application of a liquid.

Table 3. Handler Exposure Scenarios for Endosulfan [a]

Activity	Formulation Type: Emulsifiable Concentrate [b]	Formulation Type: Wettable Powder [c]
Aerial M/L [d]	x	x
Aerial Applicator	x	
Flagger	x	
Airblast M/L [d]	x	x
Airblast Applicator	x	
Airblast M/L/A [d]	x	x
Groundboom M/L	x	x
Groundboom Applicator	x	
Groundboom M/L/A	x	x
Low Pressure Handwand M/L/A	x	x
Backpack M/L/A	x	x
High Pressure Handwand M/L/A	x	x
Nursery Stock Dip/Drench M/L/A	x	x

[a] Based on product labels registered by DPR.
[b] Emulsifiable concentrate is diluted before use.
[c] Some products are packaged in water soluble packaging (WSP); separate M/L scenarios are needed for products in WSP and products not in WSP.
[d] M/L is mixer/loader. M/L/A is mixer/loader/applicator.

Reentry

Reentry scenarios considered in this EAD are shown in Appendix 1. Crops on which endosulfan is registered in California are listed in Appendix 1, along with reentry scenarios expected to occur in each. Also, the maximum application rate allowed for each use site, and the shortest pre-harvest interval (PHI) for each crop, are given in Appendix 1. PHI generally determines the earliest post-application day a crop is harvested, and is therefore considered in estimating harvester exposures. Unlike REIs, however, PHIs are set according to pesticide residues on crops rather than worker safety, and are subject to change. If a PHI is changed, the impact of that change on reentry exposure should be considered.

Reentry activity information was obtained from several sources, including the California Farm Worker Activity Profile (CFWAP; Edmiston *et al*., 1999), a survey of growers in California and surrounding states (Thompson, 1998), crop profiles published by the University of California (UCCE, 2004; VRIC, 2004), and consultation with scientists from DPR's Exposure Monitoring Program. Reentry activities include irrigating, scouting, thinning, pruning, weeding, roguing, transplanting, staking/tying, swathing, and harvesting. Irrigators may move pipes by hand in some systems, or may inspect and maintain equipment in fields. Scouts walk through fields examining leaves and other plant parts for evidence of pests or damage caused by pests. Thinning involves removal of immature fruit or plants; fruit is often thinned by hand, and crops such as lettuce and cabbage are thinned using hoes to remove excess young plants. Pruning is removal of branches and stems; depending on the crop, pruning may involve minimal or substantial contact with foliage (heavy gloves are usually worn while pruning, in contrast to thinning). Hand weeding may be done using hoes or by pulling individual plants. Roguing in cotton is removal of cotton plants that are diseased or defective, and may also be done by hand. Transplanting of young plants is done in apples, pears, and several vegetable crops if initially planted in greenhouses or nurseries. Staking and tying in tomatoes are done to keep fruit off the ground, and may be done intermittently as plants grow. Swathing in crops such as barley is done mechanically, and involves cutting plants and leaving them in windrows to dry before harvest. Harvesting is typically done mechanically in field crops, including barley and cotton; hand harvesting is done in crops, especially fruits, vegetables, and sweet corn, where product appearance is important. Fresh market tomatoes are hand harvested, while tomatoes for canning or processing into paste are harvested mechanically.

Endosulfan is registered for use on numerous crops, and many reentry activities are possible in each crop. It would be desirable to have exposure estimates for each of these crop/activity combinations (scenarios). However, little information is available for many scenarios, and several scenarios are likely to result in similar exposures. For these reasons, representative reentry exposure scenarios were selected based on available information about the extent of foliar contact for each activity, and the resulting potential for residue transfer. Residue transfer is discussed in the Exposure Assessment section.

Representative scenarios were determined by first grouping crops, then by selecting activities within each group that would be anticipated to have the highest potential for exposure. Crops were grouped by growth form (e.g., tree) and by similar cultural practices. For example, pome and stone fruit crops were grouped together, as were tree nut crops. Field crops such as cotton and barley were considered together. Lettuce and other leafy vegetables that grow close to the ground were assessed as a group. Tomatoes, eggplants and peppers, which bear fruit above ground, were considered together, as were crops such as potatoes, carrots, and sugar beets, which are underground. Strawberries and pineapples were grouped together, because their plants are fairly short and the fruit is harvested by hand. Crop groups are summarized in Table 4.

Once crops were grouped, representative activities were selected for each group; these are shown in Table 5. In Appendix 1, reentry activities listed for each site were assigned to tiers, using the following definitions based on anticipated exposure:

- Tier I: Most of the body is in contact with residues.
- Tier II: Some of the body is in contact with residues (e.g., hands, arms and face; or hands, forearms, feet, and lower legs).
- Tier III: Very little of the body is in contact with residues (e.g., hands only; or hands and feet only).

Available information about crops or groups of crops was used to determine the representative activities in Tier I and Tier II. Within each use site, suggested representative reentry scenarios are indicated in bold in the “Tier I Activities” and “Tier II Activities” columns in Appendix 1.

Table 4. Crop Groups Used for Selecting Representative Scenarios [a]

Category [b]	Representative Crop	Crops Included
FC	Cotton	Barley, Oats, Rye, Sunflower, Safflower, Wheat
FC	Corn, Sweet	Tobacco
FN	Almond	Filbert, Macadamia Nut, Pecan, Walnut
FN	Citrus	Orange, etc. (Non-bearing trees and nursery stock)
FN	Grape	(no other crops in group)
FN	Peach	Apple, Apricot, Cherry, Nectarine, Pear, Prune, Plum
FN	Strawberry	Pineapple
OT	Cut Flowers	Greenhouse Ornamentals
OT	Ornamental Plants	Nursery Stock, Trees, Shrubs
V	Broccoli	Brussels Sprouts, Cabbage, Cauliflower, Chinese Cabbage (Bok Choy), Dried Beans, Succulent Beans, Peas
V	Cucumber	Melons, Pumpkin, Summer Squash, Winter Squash
V	Lettuce	Celery, Collards, Head Lettuce, Kale, Leaf Lettuce, Mustard Greens, Spinach, Kohlrabi
V	Potato	Carrot, Sugar Beet, Sweet Potato (root vegetables)
V	Tomato	Eggplant, Peppers

[a] Crops listed in Appendix 1.
[b] FC = Field Crops; FN = Fruits and Nuts; OT = Ornamentals, Nursery/Greenhouse; V = Vegetables.

Scenarios grouped under a representative scenario are not all expected to have identical exposures; however, the representative scenario is anticipated to involve exposures similar to or greater than all scenarios covered by it. In other words, representative scenarios might overestimate exposure for other scenarios, but should not underestimate exposure. For example, cotton scouting is the representative scenario that covers all activities in alfalfa, barley, clover, oats, rye, safflower, sunflower, and wheat. Because of the height and foliar density of cotton as it matures, reentry into a treated field is likely to result in more exposure than reentry in alfalfa or most other field crops (except corn and tobacco, which are covered by another scenario). Additionally, many activities in these crops, such as irrigating or mechanical harvesting, would be anticipated to result in lower exposures per full workday than cotton scouts (see the Exposure Assessment section for an explanation of how reentry worker exposures are estimated).

For crops where the PHI is 0, 1, or 2 days, harvesting is the only representative activity assessed (under California law, REI is 2 days for all activities, including harvesting). If the PHI is longer than 2 days, a second activity is also included (e.g., thinning, pruning, staking/tying, or scouting), to ensure that the scenario having the highest exposure estimate is assessed. For most crops, hand harvesting, the activity having the greatest contact with treated foliage, can result in the highest exposure potential. However, if harvesting occurs several days after treatment (as required by longer PHI), then less foliar residue is available for transfer, which results in a lower exposure.

Table 5. Representative Reentry Scenarios for Endosulfan

Crop [a]	Rate [b]	Activity [c]	Represents [d]
Almond	2.5	Thinning (REI)	Tree nuts; all activities
Broccoli	1.0	Hand Harvest (PHI: 4)	Broccoli, etc.; all activities except scouting
Broccoli	1.0	Scouting (REI)	Broccoli, etc.; scouting
Citrus	2.5	Scouting (REI)	All activities in citrus; non-bearing trees only
Corn, Sweet	1.5	Hand Harvest (REI)	Sweet corn and tobacco; all activities
Cotton	1.5	Scouting (REI)	All field crops except sweet corn and tobacco; all activities
Cucumber	1.0	Hand Harvest (REI)	All melons, pumpkins, squash; all activities
Cut Flowers	1.0 [e]	Hand Harvest (REI)	All greenhouse plants; all activities
Grape	1.5	Cane Turning (REI)	All grapes; all activities
Lettuce	1.0	Scouting (REI)	Celery, etc.; all activities
Ornamental Plants	1.0 [e]	Hand Harvest (REI)	All nursery and container-grown ornamental plants; all activities
Peach	2.5	Thinning (REI)	Pome and stone fruits; all activities
Potato	1.0	Scouting (REI)	All root vegetables; all activities
Strawberry	2.0	Hand Harvest (REI)	All activities in strawberry
Tomato	1.0	Hand Harvest (REI)	Eggplant, peppers; all activities

[a] Representative crops from Table 4.
[b] Maximum application rate allowed on crop in pounds of active ingredient per acre (lbs AI/acre). Multiply value by 1.12 to get application rate in kg AI/ha.
[c] PHI: Pre-harvest Interval; number of days. REI: Restricted Entry Interval; REI is 2 days for all crops. In cases where PHI is 2 days or less, exposure is estimated at the expiration of the REI. In cases where the PHI is longer than 2 days, a second activity is also included to ensure that the scenario having the highest exposure estimate is assessed.
[d] All scenarios covered by the representative crop and activity are anticipated to have exposure equivalent or less than that of the representative scenario. See Table 4 for specific crops covered by each scenario.
[e] Maximum application rate for drench of ornamental plants is 1.0 lb/100 gallons (5.8 g/L).

Ambient Air, Bystander, and Swimmer

Representative scenarios for ambient air and bystander exposures include infants and adults. Representative scenarios for swimmer exposures include children and adults. Infants or children are included as potential worst-case scenarios, and exposure estimates are included for adults to allow comparison with other types of scenarios.

PHARMACOKINETICS

Dermal and Inhalation Absorption

<u>Dermal Absorption</u>

Two dermal absorption studies, conducted on rats and monkeys, are available for endosulfan (Lachman, 1987; Craine, 1988). Craine (1988) assessed dermal absorption of a 3-EC endosulfan formulation in female CD rats at doses of 0.1, 1.0 and 10 mg/kg. Applied to a 10.8-cm^2 area of shaved dorsal surface, these treatment levels provided doses of approximately 0.037, 0.37 and 3.7 mg/cm^2, respectively. The specific activity (total amount of radioactivity per unit mass) of the ^{14}C-endosulfan in the dosing solutions was either 5.47 or 27.2 microcuries/mg (µCi/mg; a microcurie equals 2.22×10^6 disintegrations per minute), and the radiopurity was 94.6%. The ^{14}C-label was located at the 5a- and 9a-carbon positions. Craine (1988) dosed 16 rats per dose level; the rats were held for 10 hrs after dosing, at which time the treated area was washed with soapy water. Animals were sacrificed at 24, 48, 72 and 168 hrs post-treatment. Radioactivities in duplicate samples, including skin at the application site, carcass and excreta (urine and feces) were quantified with liquid scintillation counting analysis, and specific activity in each sample was related to the specific activity of the appropriate dosing solution to determine percent recovery. The total percent recovery of the ^{14}C-radiolabel in the excreta, carcass, and application site at each sacrifice time period is considered to be equivalent the percent dermal absorption, as the amount recovered from the application site was considered to be potentially available for absorption. Table 6 summarizes mean results from the 168-hr period for all three doses. These data were used for the derivation of a dermal penetration value, which was used to estimate worker exposure.

Table 6. Dermal Penetration of ^{14}C-Endosulfan in Rats After 168 Hours [a]

	Applied Dose (mg/cm^2)		
	0.037	0.37	3.7
Matrix:	Percent of Applied Dose		
a) Site Wash	28.0	46.8	68.6
b) Paper Cover, Rubber Ring, Skin Wash [b]	11.9	7.9	3.2
c) Application Site	**1.7**	**1.5**	**1.0**
Excreta (Urine, Feces)	**42.3**	**44.2**	**19.0**
Carcass	**2.5**	**2.3**	**1.4**
% Penetrated [c]	46.5	48.0	21.4
% Dose Recovered (a + b + c)	86.4	102.7	93.2

[a] Data from Craine (1988).
[b] Paper cover and rubber ring protected application site. Also includes amount rinsed from skin adjacent to application site.
[c] Sum of urine, feces, application site, and carcass (values bolded). The dermal absorption estimate used in the exposure assessment is the mean penetration of the two lowest doses: (46.5 + 48.0)/2 = 47.3%.

Craine (1988) reported that amounts of ^{14}C-endosulfan recovered from the application site decreased over time, while amounts of residues in excreta increased. These trends suggest that residues bound to skin are bioavailable. For example, at 24 hrs in the low dose animals, the residues in the skin represented 41.4% of the applied dose; residues declined to 23.8% and 7.0%, respectively, at the 48-and 72-hr sacrifice time periods. Similar declines in bound skin residues occurred at the two higher treatment levels.

A portion of the bound skin residues recovered in any dermal absorption study are expected to be absorbed; as the amount that will be absorbed is unknown, standard practice is to include bound skin residues in estimates of absorbed dose (U.S. EPA, 1998c). The results from 168 hours post-dose suggest that much of the residues in the skin at 24 hours were not absorbed. Because of the large amount of residue bound to skin at 24 hours, dermal absorption can be more accurately estimated using data from 168 hours post-dose (Table 6). DPR selected the mean dermal penetration of the two lowest doses (47.3%) to estimate absorbed dosages, as the lowest doses approximate levels of endosulfan exposure experienced by handlers and fieldworkers. Total recoveries of administered doses averaged above 90%, precluding any need to adjust the estimated dermal absorption for absorbed dose recovery.

A pharmacokinetic study conducted in two male rhesus monkeys after dermal dosing with Thiodan® EC attempted to identify potential urinary metabolites for use in a worker exposure study (Lachman, 1987). Only 1.9% of the applied dose was found to be the diol, which limits its use as a biomarker for exposure. As the material balance for this study was very poor (50% of applied dose recovered), these data were not used to estimate absorbed doses.

<u>Inhalation Absorption</u>

No inhalation data are available for endosulfan. In the absence of data, DPR uses a default inhalation absorption value of 100%.

Metabolism

Most animal metabolism data for endosulfan are not contemporary, and with the exception of one study (Chan *et al*., 2005), animal metabolism studies predated Good Laboratory Practice (GLP) standards. However, the older studies help provide sufficient information to allow an adequate characterization of the pharmacokinetic and metabolic profile of this insecticide in animals. The most comprehensive metabolism study of endosulfan was reported by Dorough *et al.* (1978). They examined the fate of ^{14}C-endosulfan in rats after a single-oral dose and after feeding endosulfan in the diet for two weeks. The two-week dietary study was not used for exposure assessment in the present document.

<u>Single Oral Dose – Metabolites in Rats</u>

Female rats (number not specified, some bile cannulated) weighing 200-250 g were orally dosed with either α- or β-^{14}C-endosulfan (specific activity 0.98 mCi/mmol; radiopurity not specified) in corn oil at 2 mg/kg (Dorough *et al*., 1978). This dose was approximately 2 x 10^6 dpm/rat. The animals were held in metabolism cages for 5 days to collect urine and feces. Chloroform was the solvent used for feces extraction while diethyl ether was used to extract endosulfan metabolites from bile and urine. Following these extractions, urine samples were treated with β-glucuronidase to release conjugated metabolites. The metabolites were characterized by co-chromatography with standards in three solvent systems. The ^{14}C-material balances after five days for α- and β-endosulfan were 88.0 and 86.8%, respectively. The primary route of excretion was the feces with 74.8 and 68.3% α- and β-endosulfan, respectively. Table 7 contains the metabolic profile in feces, urine and bile after oral administration of α- and β-endosulfan. The structures of these metabolites are shown in Figure 2.

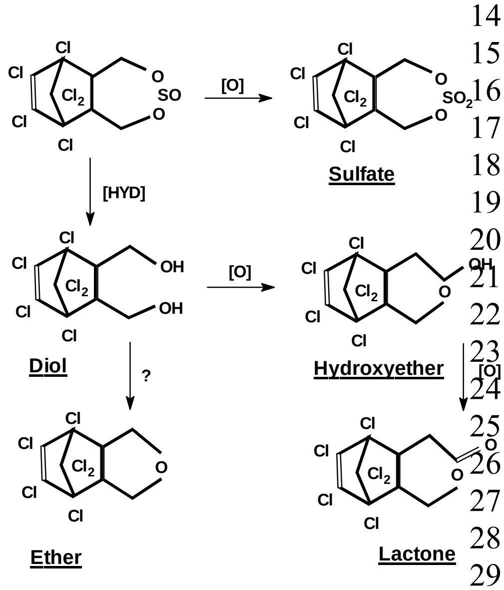
The number of metabolites in feces and urine demonstrates the lability of α- and β-endosulfan. The tissue levels in the kidney and liver of animals treated with α-endosulfan were 1.66 and 0.35 ppm, respectively. For animals treated with β-endosulfan, the tissue levels in the kidney and liver were 1.13 and 0.22 ppm, respectively. The combined liver and kidney tissue levels represented about 1.5% of the applied dose. Because the specific activity was low, residues in other tissues were not analyzed after this single oral dose. Additionally, no attempt was made to monitor $^{14}CO_2$, to determine whether endosulfan was metabolized to CO_2.

Table 7. Metabolites in Urine, Feces and Bile after a Single Oral Dose of α- or β-^{14}C-Endosulfan at 2.0 mg/kg to Female Rats [a]

	Percent of Administered Dose [b]					
	Feces [c]		Urine [d]		Bile [d]	
Metabolite	α	β	α	β	α	β
Origin (polar metabolites)	1.7	1.9	19.4	16.5	32.3	18.8
Endosulfan diol	5.3	4.1	9.1	6.4	1.3	1.0
α-Hydroxy ether	4.5	2.1	5.6	5.6	3.4	4.0
Endosulfan lactone	1.1	1.1	5.8	3.4	5.0	9.7
Endosulfan sulfate	0.3	1.2	0.0	0.0	0.0	0.0
β-Endosulfan	0.1	7.0	0.0	0.0	0.0	0.0
Endosulfan ether	0.1	0.4	0.0	0.0	0.0	0.0
α-Endosulfan	2.1	-	0.1	-	0.0	0.0

[a] Dorough *et al.* (1978). Analyzed by thin-layer chromatography.
[b] Values were not corrected for total recovery, nor was $^{14}CO_2$ monitored in this study.
[c] Extracted with chloroform.
[d] Extracted with diethyl ether.

Figure 2. Metabolic Products of Endosulfan



Recent *in vitro* studies in which endosulfan was incubated with human liver microsomes suggest that metabolism of α-endosulfan to endosulfan sulfate is catalyzed by the cytochrome P-450 enzymes CYP2B6, CYP3A4, and CYP3A5, while of formation of endosulfan sulfate from β-endosulfan is catalyzed by the latter two enzymes but not CYP2B6 (Casabar *et al*., 2006; Lee *et al*., 2006). Enzymes participating in formation of other endosulfan metabolites await identification.

<u>Pharmacokinetics After Oral Administration to Rats</u>

Chan *et al.* (2005) examined the pharmacokinetics in male Sprague-Dawley rats after a single oral dose or up to three doses of ^{14}C-endosulfan (specific activity 51.3 μCi/mg; 7:3 α- to β-isomer ratio). Groups of three 28-day-old animals were given doses of 5.0 mg/kg in olive oil by oral gavage. Six groups of animals received one dose (animals receiving repeated doses are not discussed here), and radioactivity was quantified with liquid scintillation counting analysis in blood and tissue samples for up to 4 days post-dose. In blood, the maximum concentrations occurred 2 hrs post-dose and the elimination half-life was 193 hrs. After 8 hrs, the highest amounts of radioactivity were found in liver and kidneys. The pharmacokinetics were fit by a two compartment model. Most of the radioactivity was excreted via urine (12.4% ± 4.8%) and feces (94.4% ± 21.4%), with excretion nearly complete after 48 hrs.

<u>Pharmacokinetics After Intravenous Administration to Rabbits</u>

Gupta and Ehrnebo (1979) examined the pharmacokinetics in rabbits after intravenous injection of endosulfan with a 7:3 α- to β-isomer ratio. Six female, albino rabbits (1.7-2.0 kg) were given 2.0 mg/kg, in peanut oil, through a cannulated femoral vein. Blood levels were monitored for 5 days post-administration. The blood concentration half-lives for α- and β-endosulfan were 235 ± 168 hrs and 5.97 ± 2.41 hrs, respectively. The total distribution volumes for the α- and β-isomers were found to be 675 ± 246 ml and 565 ± 126 ml, respectively. The pharmacokinetics were best fit by a three compartment model for the α-isomer and a two compartment model for the β-isomer. For the administered α-isomer, unmetabolized endosulfan was found to be 2.7% in the urine and 11% in the feces. For the β-isomer, the urine and feces contained 0.4% and 37%, unmetabolized endosulfan, respectively.

<u>Biomonitoring of Humans</u>

Limited information on excretion of endosulfan and metabolites by exposed workers was obtained from urinary samples analyzed by gas chromatography–tandem mass spectrometry (Martinez Vidal *et al*., 1998), using a method adapted for human serum that was fully described in a subsequent study by Arrebola *et al*. (2001). To validate the analytical method, urine and blood samples were collected from nine pest control operators (PCOs) in Spain. Four of the PCOs had applied pesticides the previous day, and five, the previous week. All applications lasted 2-5 hrs. Self-reported working conditions indicated lack of protective overalls, breathing masks, or gloves. Endosulfan and metabolites (endosulfan ether and endosulfan lactone) were detected in urine from all four PCOs who applied pesticides the previous day. In these four samples, α-endosulfan concentrations ranged from 787 to 894 pg/ml, and β-endosulfan concentrations ranged from 801 to 896 pg/ml. Endosulfan and metabolites (endosulfan lactone and endosulfan sulfate) were detected in urine from four of the five PCOs who applied pesticides the previous week. Concentrations were lower than in workers applying pesticides the previous day; α-endosulfan concentrations ranged from 84 to 123 pg/ml, and β-endosulfan concentrations ranged from below the detection limit of 18 pg/ml to 169 pg/ml (Martinez Vidal *et al.*, 1998). Neither endosulfan ether nor endosulfan sulfate was detected in serum samples from the workers. Endosulfan lactone was detected in one worker, at a concentration of 0.18 ng/ml. Little difference was seen in serum endosulfan levels between workers applying the previous day and those applying the previous week; α-endosulfan concentrations ranged from 3.88 to 14.54 ng/ml, and β-endosulfan concentrations ranged from 1.68 to 6.86 ng/ml (Arrebola *et al.*, 2001). No information was provided about endosulfan formulations or amounts applied, thus, relationships cannot be determined between these results and exposures. Additionally, the intermediate metabolic products, endosulfan diol and α-hydroxy ether, were not included in the assay. This study did not provide sufficient data for estimating endosulfan exposures of the PCOs.

In another study, Arrebola *et al.* (1999) collected urine samples from a single worker for three days following an endosulfan application in a greenhouse. Both α-endosulfan and β-endosulfan were detected in all samples, with concentrations ranging from 1710 – 4289 pg/ml and 491 – 1210 pg/ml, respectively. The excretion rate constant for α-endosulfan was estimated at 0.738/day, and the excretion rate constant for β-endosulfan was estimated at 0.600/day. Half-lives were calculated to be 0.940 days and 1.155 days, respectively. The metabolites endosulfan sulfate, endosulfan ether and endosulfan lactone, were not detected in any samples (detection limits ranged 6 – 18 pg/ml). Interestingly, both α-endosulfan (at 1148 pg/ml) and β-endosulfan (at 1268 pg/ml) were detected in a urine sample from a man who had not applied endosulfan (Arrebola *et al.*, 1999). This study did not provide sufficient data for estimating endosulfan exposure.

ENVIRONMENTAL CONCENTRATIONS

Dislodgeable Foliar Residues

Dislodgeable foliar residue (DFR) is defined as the pesticide residue that can be removed from both sides of treated leaf surfaces using an aqueous surfactant. DFR is assumed to be the portion of an applied pesticide available for transfer to humans from leaf and other vegetative surfaces. Measurements of DFR can be used, along with an appropriate transfer coefficient (TC; described in the Exposure Assessment section), to estimate the amount of pesticide adhering to clothing and skin surfaces following entry into a previously treated field. The DFR is reported as residue per leaf area (μg/cm^2).

Studies used for exposure estimates were evaluated for acceptability based on criteria described in Iwata *et al.* (1977) and U.S. EPA (1996). For example, each was performed under climate conditions typical of California growing season; there were no rain events during the study; samples were collected on more than one day extending at least through the REI; replicate samples were collected; residues were dislodged from leaf surfaces with a detergent solution (rather than an organic solvent); and the application rate was at or near the maximum stated on the product label for the crop (although application rates might not affect the dissipation rate, the relationship has not been studied for endosulfan).

<u>DFR Dissipation Data</u>

Willis and McDowell (1987) summarized data from three studies of dissipation of endosulfan residues in grape, pear and cotton foliage (MacNeil and Hikichi, 1976; Estesen *et al*., 1979; Wilson *et al*., 1983). However, these studies did not meet acceptability criteria described in Iwata *et al*. (1977) and U.S. EPA (1996), primarily because residues were dislodged with organic solvents rather than detergent solutions. None of these studies was used to estimate exposure.

Whitmyre *et al*. (2004) evaluated the dissipation of the EC and WP endosulfan formulations on melons, peaches and grapes in Fresno, California. A detailed report of this study was prepared by Singer (1997). The study was conducted in July through September 1995. Crops were irrigated by furrow. Applications occurred twice at 1-week intervals on melons and grapes at application rates of 1.0 and 1.5 lbs AI/acre (1.1 and 1.7 kg AI/ha), respectively, and once on peaches at 3.0 lbs AI/acre (3.4 kg AI/ha). Samples were collected at 0, 1, 3, 5 and 7 days after the first application on melons and grapes and 0, 1, 3, 5, 7, 14, 17, 21, 24, and 28 days after the second application on melons and grapes and after the first application on peaches. Residues were removed from forty 5-cm^2 leaf discs with an aqueous surfactant solution. Gas chromatography was used for quantification of α- and β-endosulfan and endosulfan sulfate; combined residues were reported. The limit of quantification was 0.01 $\mu g/cm^2$. This study met all criteria for acceptability.

Initial regression analysis of the data by Whitmyre *et al.* (2004) indicated that the decay did not follow a simple log DFR vs. time relationship. Use of a two-phase linear model for characterization of the residue decay proved to fit the data better, at least during the first several days (Whitmyre *et al.*, 2004). Dissipation of total foliar residues in cotton monitored by Kennedy *et al.* (2001) also appeared to follow a first-order function, with the initial phase relating to volatilization. However, biphasic curve fitting with a limited number of observations has a large uncertainty with respect to the inflection point. For this reason, DPR policy is to try a log-quadratic model to improve fit over the log-linear regression (Andrews, 2000). Table 8 summarizes results of log-linear and log-quadratic regressions. It is DPR policy (Andrews, 2000) to use log-linear regression unless log-quadratic gives a substantial improvement in fit (increase in R^2 of ≥ 0.05). Thus, for peach foliage following application of the 50WP formulation, the log-linear model is used; although the R^2 for the log-quadratic model is greater (0.96 vs. 0.95), the difference is just 0.01.

Mean DFR results used in regressions and predicted DFR values for selected reentry days are given in Appendix 2. Figure 3 shows the dissipation curves fitted from DFR on melon foliage following a WP application. Visual inspection of these curves confirms the results in Table 8, that the log-quadratic regression fits these data better ($R^2 = 0.97$ vs. $R^2 = 0.85$).

Table 8. Dissipation of Endosulfan on Melons, Peaches, and Grapes [a]

Crop	Formulation	Log-Linear Model [b]		Log-Quadratic Model [b]		Regression Equation with Best Fit [c]
		Adjusted R^2	MSE	Adjusted R^2	MSE	
Melons	3EC	0.77	0.253	**0.89**	**0.124**	$y = 0.0053x^2 - 0.25x - 0.95$
Melons	50WP	0.85	0.279	**0.97**	**0.054**	$y = 0.0067x^2 - 0.32x + 0.35$
Peaches	3EC	**0.70**	**0.189**	0.67	0.205	$y = -0.072x - 2.3$
Peaches	50WP	**0.95**	**0.035**	0.96	0.025	$y = -0.087x - 0.74$
Grapes	3EC	**0.56**	**0.551**	0.51	0.615	$y = -0.094x - 2.0$
Grapes	50WP	0.65	0.179	**0.71**	**0.149**	$y = 0.0031x^2 - 0.15x + 0.057$

[a] Data from Whitmyre *et al.* (2004). Applications: melons, 2 at 1.0 lb AI/acre; grapes, 2 at 1.5 lb AI/acre; peaches, one at 3.0 lbs AI/acre (1.1, 1.7, and 3.4 kg AI/ha, respectively).

[b] Regressions done in SAS 9.1 using Proc REG (SAS, 2003). MSE: mean square error. For each pair of regressions, the one giving the best fit is shown in bold; linear regression is preferred unless quadratic regression gives sufficient improvement in fit (increase in R^2 of ≥ 0.05).

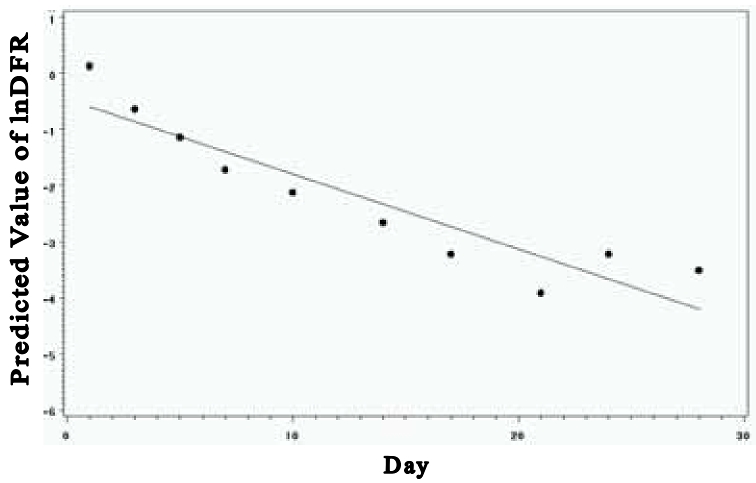
[c] Variables in equations: y = ln DFR, x = Day. See Appendix 2 for values used in exposure estimates.

Maddy *et al*. (1985a) investigated the dissipation of endosulfan on tomato, bok choy (Chinese cabbage), celery and napa cabbage in Fresno and San Luis Obispo counties. Endosulfan in an EC formulation was applied at a rate of 1.0 lb AI/acre (1.1 ka AI/ha) to all crops; applications to tomatoes were made aerially and applications to the other crops were made with a groundboom. Although it did not rain, all fields were irrigated during the study. Napa cabbage and two of the bok choy fields were irrigated with a sprinkler system, which wet the foliage and affected the DFR dissipation; data from these fields are not presented and were not used. Tomatoes, celery and one bok choy field were irrigated by furrow, which was not anticipated to affect DFR. This study met all criteria for acceptability. Table 9 summarizes DFR dissipation (combined residues of α-endosulfan, β-endosulfan and endosulfan sulfate).

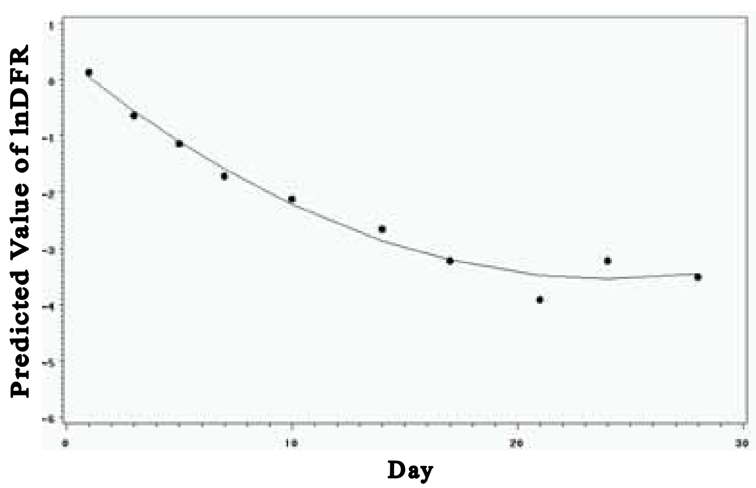
Another DFR study (data not shown) in which endosulfan was applied in an EC formulation to bok choy (Maddy *et al*., 1985b) reported similar DFR results as Maddy *et al*. (1985a). Mean DFR results used in regressions for Table 9 and predicted DFR values for selected post-application days are given in Appendix 2.

Figure 3. Endosulfan Dissipation on Melons Following a Wettable Powder Application [a]

A) Log-Linear Regression



B) Log-Quadratic Regression



[a] Data from Whitmyre *et al*. (2004). Combined residues of α-endosulfan, β-endosulfan and endosulfan sulfate.

Maddy *et al*. (1985a) investigated the dissipation of endosulfan on tomato, bok choy (Chinese cabbage), celery and napa cabbage in Fresno and San Luis Obispo counties. Endosulfan in an EC formulation was applied at a rate of 1.0 lb AI/acre (1.1 ka AI/ha) to all crops; applications to tomatoes were made aerially and applications to the other crops were made with a groundboom. Although it did not rain, all fields were irrigated during the study. Napa cabbage and two of the bok choy fields were irrigated with a sprinkler system, which wet the foliage and affected the DFR dissipation; data from these fields are not presented and were not used. Tomatoes, celery and one bok choy field were irrigated by furrow, which was not anticipated to affect DFR. This study met all criteria for acceptability. Table 9 summarizes DFR dissipation (combined residues of α-endosulfan, β-endosulfan and endosulfan sulfate).

Table 9. Dissipation of Endosulfan on Tomato, Celery, and Bok Choy [a]

Crop	Formulation	Log-Linear Model [b]		Log-Quadratic Model [b]		Regression Equation with Best Fit [c]
		Adjusted R^2	MSE	Adjusted R^2	MSE	
Tomato	3EC	0.77	0.253	**0.89**	**0.124**	y = – 0.25x – 0.95
Celery	2EC	**0.70**	**0.189**	0.67	0.205	y = – 0.072x – 2.3
Bok Choy	2EC	**0.56**	**0.551**	0.51	0.615	y = – 0.094x – 2.0

[a] Data from Maddy *et al.* (1985a). All applications were 1.0 lb AI/acre (1.1 kg AI/ha), emulsifiable concentrate formulation. Data from fields irrigated with sprinklers were omitted; only fields irrigated by furrow were included. Combined residues of α-endosulfan, β-endosulfan and endosulfan sulfate.
[b] Regressions done in SAS 9.1 using Proc REG (SAS, 2003). MSE: mean square error. For each pair of regressions, the one giving the best fit is shown in bold; linear regression is preferred unless quadratic regression gives sufficient improvement in fit. Criteria for decision in Andrews (2000).
[c] Variables in equations: y = ln DFR, x = Day. See Appendix 2 for back-transformed values from equations.

Examination of all DFR data shown in Appendix 2 allows a comparison of DFR results from Maddy *et al.* (1985a) with those from Whitmyre *et al.* (2004). The comparison shows that DFR results from fields treated with EC formulations (Maddy *et al.*, 1985a; Whitmyre *et al.*, 2004) are consistently lower than those from fields treated with WP formulations (Whitmyre *et al.*, 2004). Similarly, Rech and Edmiston (1988) obtained higher DFR results on greenhouse flower foliage treated with a WP endosulfan product than with an EC endosulfan product (data not shown). Previous comparisons between liquid and WP formulations of other pesticides have suggested that residues from WP applications might be more readily dislodgeable (Wolfe *et al.*, 1975; Spear and Popendorf, 1976). Spear and Popendorf (1976) also reported higher exposures in workers reentering crops treated by a WP than a liquid formulation. These comparisons suggest that DFR results from crops treated with WP products provide the best values to use to ensure that reentry worker exposures are not underestimated.

Table 10 summarizes DFR values that were used in reentry exposure estimates (exposure estimates are given in the Exposure Assessment section). The representative crops listed in this table are from Table 4 and application rates and days post-application are from Table 5; if these rates differed from rates used in selected studies, then DFR values used in exposure estimates were adjusted for the rate difference (i.e., multiplied by the ratio of maximum rate allowed on crop to the application rate used in the study). Surrogate crops were chosen to match representative crops as closely as possible; for example, values from peach data were used as surrogates for all tree crops. DFR values shown in Table 10 are from Appendix 2.

Table 10. Endosulfan Dislodgeable Foliar Residue (DFR) Values Used in Exposure Estimates

Crop [a]	Rate [b]	DFR for Reentry at REI [c]	DFR for Harvesting (Short-Term) [d]	DFR for Seasonal and Annual Exposure [e]		DFR from Crop [f]
				Seasonal	Annual	
Almond	2.5	0.34	Covered by thinning	NA	NA	Peach
Broccoli	1.0	0.39	0.22 (PHI: 4)	0.055 (10)	0.029 (14)	Melon
Citrus	2.5	0.34	Not applicable [g]	NA	NA	Peach
Corn, Sweet	1.5	0.58	0.58 (PHI: 1/REI: 2)	NA	0.082 (10)	Melon
Cotton	1.5	0.58	Covered by scouting	0.082 (10)	NA	Melon
Cucumber	1.0	0.39	0.39 (PHI: 2)	NA	0.055 (10)	Melon
Cut Flowers	1.0	0.42	0.42 (PHI: 0/REI: 2)	NA	NA	Grape
Grape	1.5	0.62	Covered by cane turning	0.26 (10)	NA	Grape
Lettuce	1.0	0.39 [h]	Covered by scouting	0.055 (10)	NA	Melon
Ornamental Plants	1.0	0.42	0.42 (PHI: 0/REI: 2)	NA	NA	Grape
Peach	2.5	0.34	Covered by thinning	0.17 (10)	NA	Peach
Potato	1.0	0.39	Covered by scouting	0.055 (10)	NA	Melon
Strawberry	2.0	0.83	0.83 (PHI: 1/REI: 2)	NA	NA	Grape
Tomato	1.0	0.39	0.39 (PHI: 2)	NA	0.055 (10)	Melon

[a] Representative crops from Table 4.
[b] Maximum application rate allowed on crop in pounds of active ingredient per acre (lbs AI/acre), from Table 5. Multiply value by 1.12 to get application rate in kg AI/ha. If DFR came from a study with a different application rate, then DFR values used in exposure estimates were adjusted for the rate difference (i.e., DFR was multiplied by the ratio of maximum rate allowed on crop to rate used in study).
[c] DFR values ($\mu g/cm^2$) used for short-term exposure estimates for workers entering at expiration of Restricted Entry Interval (REI); under California regulation, REI is 2 days for all crops.
[d] DFR ($\mu g/cm^2$) estimated for expiration of preharvest interval (PHI). If PHI is less than 2 days, REI of 2 days is used. DFR values used for short-term exposure estimates for harvesters.
[e] DFR ($\mu g/cm^2$) estimated for non-harvest activities/harvesting. Reentry at post-application day in parentheses. NA = not applicable.
[f] Crops and DFR equations shown in Table 8. Surrogate crops were chosen to match representative crops as closely as possible. Unless otherwise noted, values used are from wettable powder data in Appendix 2.
[g] Endosulfan use is only allowed on non-bearing citrus; hence, there is no fruit to harvest.
[h] A DFR sample mean of 2.0 $\mu g/cm^2$ from Hernandez *et al*. (2002) was substituted for this value (see Table 11).

<u>DFR Studies with Spot Sampling of Crop Foliage</u>

Two studies are available in which spot samples of crop foliage were collected and DFR analyzed; both were done in California by DPR. As part of a large study of pesticide residues encountered by reentering fieldworkers, Hernandez *et al.* (1998) collected and analyzed 939 foliar samples in sixteen counties in California's Central Valley and coastal regions. No information was available about pesticide applications; samples were tested for multiple pesticides. Endosulfan was detected in 33 samples, at levels ranging from 0.002 to 0.172 $\mu g/cm^2$. Reported detection limits for pesticides in leaf disc extract samples ranged from 2 – 12 μg/sample. Each sample contained residues dislodged from either 405 or 423 cm^2 of leaf surface, depending on the leaf punch used (Hernandez *et al.*, 1998); thus, the reported detection limits for endosulfan ranged 0.005 – 0.030 $\mu g/cm^2$.

In another study, DFR samples were collected at the expiration of the REI following known pesticide applications (Hernandez *et al.*, 2002). Endosulfan was detected in 128 of a total of 139 samples. Table 11 summarizes results of the study for endosulfan. Although application dates were reported by Hernandez *et al.* (2002), application rates and formulations were not. It is possible that some variability in DFR results summarized in Table 11 are due to differences in application rates or formulations.

Table 11. Dislodgeable Foliar Residues of Endosulfan on Samples Collected from 1998 through 2001 [a]

Crop	Sampling Date [b]	Number of Detects/Total Samples	Minimum detected DFR [c] (μg/cm²)	Maximum DFR (μg/cm²)	Mean DFR [c] (μg/cm²)	SD DFR [c] (μg/cm²)
Broccoli	10/30/1998	16/16	0.079	0.2575	0.1374	0.0512
Broccoli	10/4/2000	6/6	0.0084	0.0201	0.0142	0.0005
Cauliflower	5/10/2001	0/4	ND	ND	ND	ND
Lettuce, Butter	3/27/1999	8/8	0.0405	0.5350	0.2741	0.1714
Lettuce, Head	3/28/1999	1/8	0.115	0.115	- -	- -
Lettuce, Head	4/1/1999	12/12	0.0720	0.1543	0.1189	0.0285
Lettuce, Head	3/19/2000	11/11	0.2155	1.5575	0.9244	0.4389
Lettuce, Head	3/21/2000	9/9 [d]	1.1025	2.435	2.0283 [e]	0.0142
Lettuce, Head	10/3/2000	10/10	0.0630	0.7725	0.3737	0.3466
Lettuce, Head	3/25/2001	10/10	0.5125	1.640	1.186	0.3375
Lettuce, Leaf	3/31/1999	18/18	0.0432	0.1248	0.0786	0.0214
Lettuce, Leaf	10/2/2000	10/10	0.0403	0.2465	0.1397	0.0590
Radicchio	3/30/1999	8/8	0.0765	0.2940	0.1566	0.0851
Tomato	8/21/2000	9/9	0.1960	0.7175	0.4353	0.2772

[a] Data from Table 1 and Appendix 1 in Hernandez *et al.* (2002). ND: Not detected.
[b] Samples collected within 24 hrs of expiration of the 48-hr restricted entry interval for endosulfan.
[c] Non-detects excluded from range and statistics. Reported detection limits ranged from 2 – 12 μg/sample.
[d] Although ten samples were collected, only nine were analyzed according to the laboratory sample tracking form; Sample Fd00-0021 was marked as "lost."
[e] This mean DFR result (the highest single-day mean) was used in estimating reentry exposure at the expiration of the restricted entry interval for lettuce and crops grouped with lettuce (see Table 10).

Most of the mean results in Table 11 are lower than DFR values listed in Table 10. However, mean DFR results from head lettuce samples ranged from 0.0786 to 2.0283 μg/cm²; three of the six head lettuce samples had mean DFRs above the estimated DFR of 0.39 μg/cm² listed in Table 10. Because of this, the highest daily mean value of 2.0 μg/cm², from 3/21/2000, was used in short-term exposure estimates for reentry workers in lettuce. This single-day mean DFR was used, rather than an overall mean incorporating multiple days, because the application rates for most of the fields sampled in this study are unknown. It's possible that the samples collected on days other than 3/21/2000 followed lower application rates. However, a query of PUR data from applications to head lettuce in Fresno County, for the interval spanning 1 – 3 days before the sample collection date, show no applications exceeding the allowed rate of 1.0 lb AI/acre (sampling on 3/21/2000 occurred in Fresno County, based on information in the study project file). This suggests that the mean DFR value of 2.0 μg/cm² is not the result of an application rate above the maximum rate allowed; based on available data, this result is considered the best DFR value to use in estimating reentry exposure. To rely instead on surrogate data from the dissipation study conducted in melons would underestimate exposure.

In contrast to lettuce, the mean DFR of 0.4335 μg/cm^2, from tomato foliage sampled on 8/21/2000, is very close to the estimated DFR of 0.39 μg/cm^2 given in Table 10. This suggests that foliar residues on melons are a better surrogate for residues on tomato foliage than for residues on lettuce.

A study was submitted to U.S. EPA in which DFR dissipation was determined on apples, apricots, processing tomatoes, and cherry tomatoes (U.S. EPA, 2002b). The study was unacceptable because of poor field recoveries, variable laboratory recoveries, and missing storage and meteorological information. This study was not available to DPR.

Air

As summarized by Burgoyne and Hites (1993), endosulfan has been detected in air samples collected throughout the world, including urban and unpopulated areas, where endosulfan applications are unlikely, as well as agricultural areas where endosulfan is used. In long-term air monitoring conducted in Indiana, endosulfan was detected only in the vapor phase, never on particulate samplers, and generally the only isomer detected was α-endosulfan, with β-endosulfan detected in only two samples (Burgoyne and Hites, 1993). Conversely, particle-bound endosulfan was detected in monitoring conducted elsewhere in the eastern U.S. and in Europe and Asia (Gioia *et al*., 2005; Scheyer *et al.*, 2005; Sun *et al*., 2006; Li *et al*., 2007). Concentrations of α-endosulfan increased with atmospheric temperature. Summarizing several studies comparing the isomers, Schmidt *et al.* (2001) reported that α-endosulfan is the more prevalent isomer in air samples, a trend that is consistent with data reported below. Rice *et al.* (2002) found that α-endosulfan was more volatile than β-endosulfan following application to a fine-silty loam. Kennedy *et al.* (2001) investigated dissipation of endosulfan following application to cotton fields in Australia (> 50% clay, 17-25% silt, 13-30% sand, ≤ 1% organic carbon), and found that up to 70% of the endosulfan applied volatilized within 5 days of the application.

California has laws intended to limit ambient air concentrations of pesticides, including the Toxic Air Contaminants Act (California Health and Safety Code, Sections 39650-39761), which codified the state program to evaluate and control toxic air contaminants (TAC). A pesticide is placed on the TAC list if its concentrations in ambient air have been determined to be within an order of magnitude of the concentration determined to cause human health effects (3 CCR 6890). Endosulfan is a candidate for inclusion on the TAC list (Sanders, 1997). In California, endosulfan concentrations have been monitored in the ambient air during peak application season and in the air surrounding application sites. These studies are discussed below.

<u>Ambient Air</u>

DPR monitored ambient air concentrations of several pesticides, including endosulfan, in Monterey County in June 1985 (Sava, 1985). Monitoring was done at three sites in residential areas located near agricultural land. Site 1 was 1200 ft (370 m) from artichoke fields; Site 2 was 190 ft (58 m) from a fallow field; and Site 3 was located 50 ft (15 m) from a lettuce field. Sample devices consisted of XAD-2 resin in two tubes, connected with a tee fitting to air pumps calibrated to 32 L/min. During sampling, air was pumped through the samplers for 6 hrs; twelve samples were collected at each site. Of the 36 samples, 30 were below the minimum detection limit of 0.009 $\mu g/m^3$ for α-endosulfan; concentrations of α-endosulfan in the six samples (four at Site 1, two at Site 2) ranged from 0.034 to 0.051 $\mu g/m^3$ (Sava, 1985). Neither β-endosulfan nor endosulfan sulfate was detected; minimum detection limits were 0.017 $\mu g/m^3$ and 0.052 $\mu g/m^3$, respectively.

In 1996, ambient air monitoring of endosulfan concentrations was conducted in Fresno County by the Air Resources Board (ARB) of the California Environmental Protection Agency (ARB, 1998). Air samples were collected during a 5-week interval, from July 29 through August 29, at four sites near cotton and grape growing areas where endosulfan applications might be anticipated (although whether applications actually occurred near all sampling locations during the sampling interval was not reported), and at an urban (background) site. The ambient sites were in populated areas at the following locations: Cantua Creek School in Cantua Creek (Site CC); Westside Elementary School in Five Points (Site WE); San Joaquin Elementary School in San Joaquin (Site SJ); and Tranquility High School in Tranquility (Site TQ). The background site was an ARB Ambient Air Monitoring Station in Fresno (Site ARB). Except for Site ARB, which was above a two-story building, samplers were positioned about 1.5 m above roof tops of single-story buildings. Each air sampler consisted of a glass tube containing two sections of XAD-2 sorbent, with glass wool plugs on each end and separating the sorbent sections; tubes were connected to air pumps calibrated at 2.0 L/min.

Quality assurance consisted of blanks, collocated samples, and spiked samples (sample tubes spiked with known amounts of α- and β-endosulfan). Blanks and spikes were handled as follows: trip blanks and spikes were carried to the background site and kept in the sample cooler until their return to the laboratory for analysis; laboratory blanks and spikes were stored in the laboratory until analysis; and field blanks and spikes were carried to the background site, connected to sampling pumps collocated with background samples, and handled and stored with samples. Neither α- nor β-endosulfan was detected in the single trip blank, laboratory blank, or duplicate collocated field blanks. Duplicate collocated samples were collected at all sites weekly, and differed by 0 – 37%; all but six samples differed by less than 10%. In laboratory, trip, and field spikes, α-endosulfan was spiked at either 0.0084 or 0.118 µg/sample, and β-endosulfan was spiked at 0.027 µg/sample.

Table 12 summarizes recoveries from the spiked samples. Recoveries of α-endosulfan were low in all spikes, with trip spikes ranging 0 – 23%; laboratory spikes ranging 38 – 41%; and field spikes ranging 38 – 54% (Table 12). Recoveries of β-endosulfan for trip, laboratory, and field spikes ranged 0 – 74%, 96 – 111%, and 81 – 85%. A follow-up quality assurance audit reviewed analytical records, laboratory procedures, spiking procedures, and records of how spiking solutions were shipped, stored, and handled. Spiking solutions were purchased from commercial sources, and were stored at 4°C;

however, the manufacturers recommended storage at room temperature. As a result of solutions being chilled, it is possible that α-endosulfan might have adhered to walls of the solution containers. The quality assurance audit was unable to substantiate the basis for low α-endosulfan recoveries, and recoveries of α-endosulfan during the 20-day storage stability study were 103 $\pm$ 1%.

Table 12. Recoveries of α- and β-Endosulfan from Laboratory, Trip, and Field Spikes During Ambient Air Monitoring Conducted in 1996 [a]

Spikes	α-endosulfan Amount Spiked (µg)	α-endosulfan Amount Recovered (µg) [b]	α-endosulfan Percent Recovered (%) [c]	β-endosulfan Amount Spiked (µg)	β-endosulfan Amount Recovered (µg) [b]	β-endosulfan Percent Recovered (%) [c]
Laboratory Spikes [d]						
Blank	0	ND	NA	0	ND	NA
Low	0.0084	ND	0	0	ND	NA
Medium	0.0420	0.0160	38	0.0270	0.0300, 0.0290	109
High	0.1176	0.0450, 0.0480	40	0.0270	0.0260, 0.0280	100
Trip Spikes [e]						
AccuStandard						
Blank	0	ND	NA	0	ND	NA
Low	0.0084	ND	0	0	ND	NA
High	0.1176	0.012	10	0.0270	ND	0
Axact Standard						
Blank	0	ND	NA	0	ND	NA
Low	0.0084	ND	0	0	ND	NA
High	0.1176	0.040, 0.042	35	0.0270	0.0200, 0.0190	72
Field Spikes [f]						
Blank	0	ND	NA	0	ND	NA
Low	0.0084	0.0045, 0.0039	50	0	ND	NA
High	0.1176	0.045	38	0.0270	0.0230, 0.0220	83

[a] Data from ARB (1998). Results for endosulfan sulfate omitted. All spikes were prepared from a commercially purchased solution from AccuStandard. An extra set of trip spikes was prepared from a commercially purchased solution from Axact Standard.

[b] Results of two spiked samples (only one blank was included). If a single result is reported, both spikes had the same amount. The analytical limit of detection was 0.0033 µg/sample extract for α-endosulfan and 0.011 µg/sample extract for β-endosulfan. Sample extract volume was 3.0 ml.

[c] Mean of duplicate spiked samples.

[d] Laboratory spikes were prepared in the laboratory and stored until analysis; their purpose was to test for potential contamination or analyte loss during sample storage and analysis.

[e] Trip spikes were prepared in the laboratory, carried to the background site, and back to the laboratory; their purpose was to test for potential contamination or analyte loss during sample transport and storage.

[f] Field spikes were prepared in the laboratory, carried to the background site, connected to sampling pumps collocated with background samples; their purpose was to test for potential contamination or analyte loss during the entire sampling process. Mean recovery of α-endosulfan was (50 + 38)/2 = 44%.

Table 13 summarizes monitoring results. Italicized values in Table 13 are results that were below the limit of quantification (LOQ), which varied according to the volume of air sampled. The LOQ was calculated by multiplying the analytical limit of detection (LOD) by the sample extract volume and by 3.3 (LOQ was set at 3.3 times the LOD); this was then divided by the volume of air sampled. The analytical LOD was 0.0033 μg/sample for α-endosulfan and 0.011 μg/sample for β-endosulfan. The sample extract volume was 3.0 ml for all samples, and the volume of air sampled ranged from 2.20 – 4.15 m^3. According to standard DPR practice, results of ambient air monitoring were corrected for α- and β-endosulfan average field spike recoveries of 44% and 83%, respectively. Results < LOQ were not corrected for field spike recoveries; ½ LOQ was substituted for results < LOQ.

Figure 4 shows the monthly use of endosulfan reported in Fresno County in 1996. Nearly 80% of endosulfan use in 1996 occurred during the three-month period of June – August. As monitoring began in late July and continued throughout August, all sampling occurred in that high-use period. However, use in June and July was higher than in August, suggesting that the highest ambient air concentrations might not have occurred during the monitoring.

Of the 75 samples collected at the four stations (excluding the background site), nine were below the LOQ for α-endosulfan, which ranged from 0.0037 to 0.0043 μg/m^3; concentrations of α-endosulfan in the other samples ranged from 0.0095 to 0.318 μg/m^3. For β-endosulfan, only two of the 75 samples were above the LOQ (0.0086 – 0.015 μg/m^3); concentrations in these samples were 0.016 and 0.031 μg/m^3. None of the background samples collected at Site ARB had α-endosulfan or β-endosulfan concentrations above the LOQ.

In addition to α-endosulfan and β-endosulfan, sample extracts were analyzed for endosulfan sulfate. The analytical LOD for endosulfan sulfate was 0.019 μg/sample. Endosulfan sulfate was not detected in any sample, and is not included in Table 13.

Ambient air monitoring of several pesticides, including α-endosulfan, β-endosulfan, endosulfan sulfate, was also conducted in May to September 1996 at three sites in Tulare County (LeNoir *et al*., 1999). Elevations of the sample stations were provided as the study was intended to monitor up-slope movement of pesticides used in the Central Valley into the Sierra Nevada Mountains. The first site was at the Kaweah Dam (Site KD), at a reported elevation of 200 m above sea level. The other two sites were in the Sierra Mountains, on Ash Mountain (Site AM, elevation 553 m) and Lower Kaweah (Site LK, elevation 1920 m).

Duplicate 8-hour (daytime) air samples were collected monthly at each site. Paired samplers were positioned 2 m apart and 1 m above ground. Each air sampler consisted of a stainless steel tube with 100-mesh screens on either end (which allow passage of particles with diameters up to approximately 149 μm), containing 150 ml of pre-cleaned XAD-4 resin and connected to a flowmeter and a high flow sampling pump with nominal flow rate of 700 L/min. The LOQ (three times the reported LOD) was 0.0000018 μg/m^3, 0.000003 μg/m^3, and 0.0000027 μg/m^3, respectively, for α-endosulfan, β-endosulfan, and endosulfan sulfate. Quality assurance consisted of duplicate samples and spikes through which air was drawn for 8 hr. Average spike recovery was 83% for α-endosulfan, 80%

for β-endosulfan, and 75% for endosulfan sulfate. Results, corrected for these spike recoveries, are summarized in Table 14.

Table 13. Endosulfan Concentrations in Ambient Air Monitoring in Fresno County [a]

Date	Site CC [b]		Site SJ		Site TQ		Site WE		Site ARB	
	α [c]	β [c]	α	β	α	β	α	β	α	β
July 29	0.019	*0.0071*	0.039	*0.0068*	0.048	*0.0068*	0.019	*0.0069*	*0.0025*	*0.0081*
July 30	0.066	*0.0061*	0.036	*0.0063*	0.045	*0.0066*	0.052	*0.0060*	*0.0020*	*0.0066*
July 31 [d]	0.078	*0.0062*	0.027	*0.0062*	0.033	*0.0062*	0.034	*0.0062*	*0.0019*	*0.0062*
August 1	0.023	*0.0062*	0.036	*0.0062*	0.016	*0.0062*	0.032	*0.0062*	*0.0019*	*0.0062*
August 5	0.061	*0.0067*	0.010	*0.0065*	0.093	*0.0066*	NS [e]	NS	*0.0023*	*0.0074*
August 6	0.055	*0.0062*	0.080	*0.0062*	0.159	*0.0062*	0.034	*0.0062*	*0.0019*	*0.0062*
August 7 [d]	0.052	*0.0064*	0.284	0.016	0.077	*0.0064*	0.032	*0.0064*	*0.0020*	*0.0064*
August 8	0.039	*0.0062*	0.318	0.031	0.080	*0.0063*	0.039	*0.0064*	*0.0020*	*0.0064*
August 12	0.041	*0.0063*	0.030	*0.0067*	0.018	*0.0066*	0.018	*0.0043*	*0.0023*	*0.0076*
August 13	0.045	*0.0063*	0.043	*0.0063*	0.039	*0.0062*	0.023	*0.0063*	*0.0019*	*0.0062*
August 14 [d]	0.032	*0.0062*	0.021	*0.0062*	0.021	*0.0062*	0.013	*0.0062*	*0.0019*	*0.0062*
August 15	0.020	*0.0062*	0.025	*0.0062*	0.102	*0.0062*	0.0095	*0.0062*	*0.0019*	*0.0062*
August 19	0.021	*0.0065*	*0.0020*	*0.0066*	0.013	*0.0062*	0.010	*0.0065*	*0.0019*	*0.0062*
August 20	0.020	*0.0062*	0.020	*0.0063*	0.027	*0.0063*	0.013	*0.0062*	*0.0020*	*0.0063*
August 21 [d]	0.015	*0.0063*	0.024	*0.0063*	0.038	*0.0063*	0.011	*0.0063*	*0.0020*	*0.0068*
August 22	NS [e]	NS	NS	NS	NS	NS	NS	NS	NS	NS
August 26	*0.0024*	*0.0069*	*0.0019*	*0.0068*	*0.0021*	*0.0069*	*0.0021*	*0.0069*	*0.0025*	*0.0080*
August 27	*0.0019*	*0.0060*	*0.0019*	*0.0062*	0.013	*0.0062*	*0.0019*	*0.0062*	*0.0017*	*0.0053*
August 28 [d]	0.010	*0.0065*	0.0095	*0.0061*	0.013	*0.0060*	*0.0019*	*0.0060*	*0.0023*	*0.0074*
August 29	0.011	*0.0068*	0.023	*0.0064*	0.043	*0.0065*	0.012	*0.0065*	*0.0020*	*0.0065*
Mean [f]	0.032	0.0064	0.054	0.0082	0.046	0.0064	0.020	0.0062	0.0020	0.0066
SD [f]	0.022	0.0003	0.089	0.0060	0.040	0.0002	0.014	0.0005	0.0002	0.0007

[a] Monitoring conducted in 1996 (ARB, 1998). Concentrations are reported in μg/m^3. For results below the limit of quantification (LOQ), ½ LOQ was reported; these values are italicized. The LOQ for each sample was dependent on the volume of air sampled. The analytical limit of detection was 0.0033 μg/sample extract for α-endosulfan and 0.011 μg/sample extract for β-endosulfan. Sample extract volume was 3.0 ml. Results above the LOQ were corrected for field spike recoveries of 44% for α-endosulfan and 83% for β-endosulfan.

[b] Site CC: Cantua Creek School, Cantua Creek. Site SJ: San Joaquin Elementary School, San Joaquin. Site TQ: Tranquility High School, Tranquility. Site WE: Westside Elementary School, Five Points. Site ARB: background site at the ARB Ambient Air Monitoring Station, Fresno.

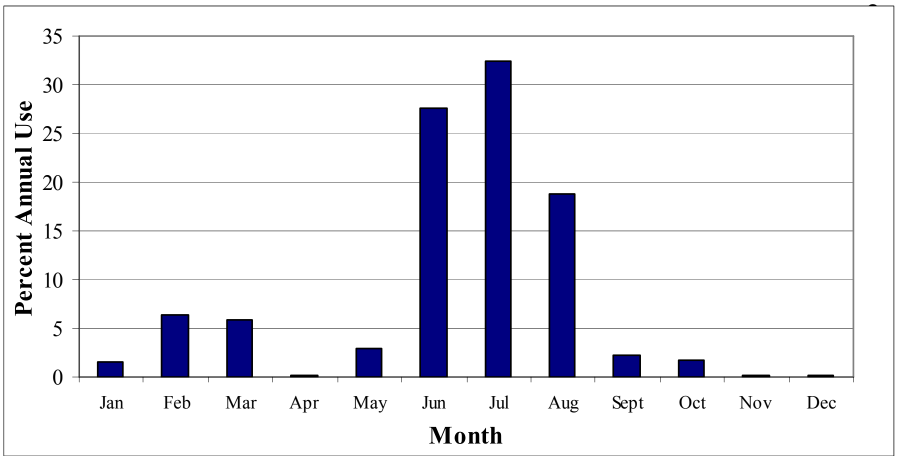
[c] α: α-endosulfan. β: β-endosulfan.

[d] Collocated duplicate samples. Mean reported.

[e] NS: No sample on this date, due to instrument malfunction.

[f] Arithmetic mean and standard deviation (SD).

Figure 4. Monthly Use of Endosulfan in Fresno County, 1996 [a]



[a] Percent calculations based on pounds applied by all methods to all crops in Fresno County (DPR, 2006a; queried January 26, 2006).

Table 14. Endosulfan Concentrations in Ambient Air Monitoring in Tulare County [a]

Date	Site KD [b]			Site AM			Site LK		
	α [c]	β [c]	Sulfate [c]	α [c]	β [c]	Sulfate [c]	α [c]	β [c]	Sulfate [c]
5/30/96	0.00442	0.00022	0.00001	0.00129	0.00009	0.00001	NS	NS	NS
6/25/96	0.00139	0.00042	0.00001	0.00064	0.00016	0.00001	NS	NS	NS
7/10/96	0.00277	0.00050	0.00007	0.00181	0.00024	0.00005	0.00183	0.00029	0.00004
8/16/96	0.00136	0.00034	0.00007	NS [d]	NS	NS	0.00066	0.00011	0.00003
9/21/96	0.00161	0.00080	0.00009	0.00063	0.00015	0.00003	0.00036	0.00018	0.00003
Mean [e]	0.0023	0.00046	0.00005	0.00109	0.00016	0.00003	0.00095	0.00019	0.00003
SD [e]	0.0013	0.00022	0.00004	0.00057	0.00006	0.00002	0.00078	0.00009	0.00001

[a] Results of duplicate samples; duplicates differed by < 40% (LeNoir *et al.*, 1999). Concentrations are reported in μg/m^3, and were corrected for mean spike recoveries: 83% for α-endosulfan, 80% for β-endosulfan, and 75% for endosulfan sulfate. All results were above the limit of quantification (LOQ). LOQ for α-endosulfan: 0.0000018 μg/m^3. LOQ for β-endosulfan: 0.000003 μg/m^3. LOQ for endosulfan sulfate: 0.0000027 μg/m^3.

[b] Site KD: Kaweah Dam, 200 m elevation. Site AM: Ash Mountain in the Sequoia National Park, 553 m elevation. Site LK: Lower Kaweah in the Sequoia National Park, 1920 m elevation. Samplers were positioned 1 m above ground.

[c] α: α-endosulfan. β: β-endosulfan. Sulfate: endosulfan sulfate.

[d] NS: No sample collected on this date.

[e] Arithmetic mean and standard deviation (SD).

Site KD is adjacent to citrus orchards, while Site AM was about 18 km east of Site KD and Site LK is 10 km northeast of Site AM. Both Site AM and Site LK are located in the Sequoia National Forest. Although these sites are not adjacent to cropland, the summertime winds are predominantly from the northwest, and all three sites are downwind of croplands in Tulare and Fresno counties (LeNoir *et al*., 1999). However, concentrations measured at these sites were lower than those measured in Fresno County.

Application Site Air

ARB monitored endosulfan concentrations in air near an airblast application of endosulfan to a 6-acre (2.4-ha) apple orchard in San Joaquin County in 1997 (ARB, 1998). Endosulfan in a WP formulation was applied at a rate of 1.5 lb AI/acre (1.7 kg AI/ha). The orchard was L-shaped, and three air monitoring stations were located along the "outer" edges of the "L". These stations, designated the E, W, and S stations, respectively, were approximately 6.4 m from the eastern edge; 10 m from the western edge; and 8.2 m from the southern edge. The N station was located inside the angle of the L-shape, about 16.5 m west and 86 m north of the inside edges of the orchard, and about 12.8 m south of the northernmost edge of the orchard. The W, S, and N samplers were at the same elevation as the orchard while the E sampler was on a levee about 1 m higher than the orchard. Each air sampler consisted of a glass tube containing two sections of XAD-2 sorbent, with glass wool plugs on each end and separating the sorbent sections; tubes were connected to air pumps calibrated at 2.0 L/min. Duplicate collocated samples were collected at the S station. The application took place on April 8 between 5:45 and 7:45 AM. Samples were collected from April 8, the day of application, through April 11.

Quality assurance was generally acceptable during application site monitoring. Neither α- nor β-endosulfan was detected in the single trip blank, laboratory blank, or duplicate collocated blanks. Duplicate collocated samples were collected at all sites weekly, and differed by 0 – 36% for α-endosulfan (average concentrations from collocated samples were 0.066 – 1.25 μg/m^3) and 18 – 80% for β-endosulfan (concentrations from collocated samples ranged < LOD – 0.083 μg/m^3). In laboratory, trip, and field spikes, α-endosulfan and β-endosulfan were each spiked at 0.050 μg/sample. Recoveries of α-endosulfan were acceptable, with trip spikes ranging 78 – 83%; laboratory spikes ranging 80 – 90%; and field spikes ranging 81 – 90%. Recoveries of β-endosulfan were acceptable, and for trip, laboratory, and field spikes ranged 59 – 66%, 58 – 66%, and 57 – 66%, respectively. Table 15 summarizes results of application site monitoring. As a health-protective measure, results were corrected for α- and β-endosulfan average field spike recoveries of 85% and 60%, respectively.

A time-weighted average (TWA) concentration was calculated for the first day, starting with the hour during which the application occurred (i.e., 26.75 hours of monitoring). Also, 3-day TWA concentrations were calculated by including monitoring from the two post-application days. These TWA values were used in estimating short-term and seasonal bystander exposures, respectively (see the Exposure Assessment section).

Of the 75 samples collected at the four stations (excluding the background site), nine were below the LOQ for α-endosulfan, which ranged from 0.0037 to 0.0043 μg/m^3; concentrations of α-endosulfan in the other samples ranged from 0.0095 to 0.318 μg/m^3. For β-endosulfan, only two of the 75 samples were above the LOQ (0.0086 – 0.015 μg/m^3); concentrations in these samples were 0.016 and 0.031 μg/m^3. None of the background samples collected at Site ARB had α-endosulfan or β-endosulfan concentrations above the LOQ.

In addition to α-endosulfan and β-endosulfan, sample extracts were analyzed for endosulfan sulfate. Endosulfan sulfate was below the LOQ in all samples, though above the LOD in seven samples. Because endosulfan sulfate results were all below the LOQ, endosulfan sulfate is not included in Table 15.

Table 15. Endosulfan Concentrations (µg/m^3) Near an Apple Orchard Receiving an Application by Airblast [a]

Date and time of monitoring in 1997	West		North		East		South [b]		Wind Speed [c]	Wind Direction
	α [d]	β [d]	α	β	α	β	α	β		
April 8, 0530-0845 [e]	0.336	*0.048*	0.618	0.125	0.631	0.122	0.504	0.125	0 – 6	W
April 8, 0845-1040	0.051	*0.043*	0.535	*0.045*	2.09	0.152	0.563	*0.043*	3 – 7	W
April 8, 1040-1440	0.024	*0.021*	0.840	0.068	4.56	0.340	1.45	0.087	0 – 4	W
April 8, 1440-2245	0.012	*0.010*	0.509	0.052	1.47	0.122	0.146	*0.010*	1 – 17	W/SW
April 8-9, 2245-0815	*0.004*	*0.009*	0.103	*0.009*	0.432	0.029	0.077	*0.009*	3 – 13	W/SW
24-hour TWA [f]	0.053	0.022	0.429	0.047	1.51	0.124	0.389	0.037	NA	NA
Total Endosulfan TWA [g]	0.075		0.477		1.63		0.426		NA	NA
April 9-10, 0815-0800	0.021	*0.004*	0.095	0.012	0.578	0.058	0.485	0.059	0 – 9	W/NW/N
April 10-11, 0800-0800	0.004	*0.003*	0.065	*0.003*	0.449	0.064	0.349	0.064	0 – 10	NW/N/NE
3-day TWA [h]	0.027	0.010	0.205	0.025	0.870	0.084	0.407	0.053	NA	NA
Total Endosulfan TWA [i]	0.037		0.231		0.952		0.460		NA	NA

[a] Stations ranged from 6.4 – 16.5 m from orchard edges during an application of 1.7 kg AI/ha (ARB, 1998). Concentrations are reported in µg/m^3; background concentrations were below the limit of quantification (LOQ) and are not shown. For results below the LOQ, ½ LOQ was reported; these values are italicized. LOQ dependent on volume of air sampled; analytical limit of detection was 0.00112 µg/ml sample extract for α-endosulfan and 0.0036 µg/ml sample extract for β-endosulfan. Each sample consisted of 1.0 ml sample extract. Results above the LOQ were corrected for field spike recoveries of 85% for α-endosulfan and 60% for β-endosulfan.

[b] Mean of two stations.

[c] Wind speed in miles/hr, from Appendix VII in ARB (1998). NA: not applicable.

[d] α: α-endosulfan. β: β-endosulfan.

[e] Air monitoring during application. Subsequent measures are post-application.

[f] Time-weighted average (TWA) concentration over first 24 hours, beginning with application at 5:30 AM and ending with sample completed 24.5 hours post-application. Samples taken during 26.75 hours were used as an approximation for the 24-hour TWA. For results below the LOQ, ½ LOQ was used in calculations.

[g] Total endosulfan concentration calculated by adding α- and β-endosulfan concentrations together for each sample. 24-hour TWA based on samples taken during the 26.75 hours starting with the application.

[h] 3-day TWA on samples taken during the 74.5 hours starting with the application, calculated as above.

[i] Total endosulfan 3-day TWA calculated by adding α- and β-endosulfan concentrations together for each sample.

Water

In laboratory experiments conducted by Peterson and Batley (1993), α-endosulfan consistently degraded faster than β-endosulfan; both isomers hydrolyzed faster in alkaline waters than in water close to pH 7. Half-lives in pH 8.5 water at 20°C were 3.6 days for α-endosulfan and 1.7 days for β-endosulfan. As β-endosulfan is less water soluble than α-endosulfan, it is more likely to partition to sediment as well.

Endosulfan has been monitored in both surface and ground water in California, and in tissues of fish and aquatic invertebrates. The monitoring data relevant to human exposure to endosulfan include surface waters where swimming or wading may occur (e.g., rivers or farm ponds), as well as surface and ground water sources of drinking water in California. Endosulfan residues occurring in drinking water could potentially result in exposure through swimming or bathing (dietary exposure is beyond the scope of this EAD).

<u>Surface Water</u>

Historically, endosulfan has been detected numerous times in California surface waters. Guo and Spurlock (2000) summarized historical monitoring data, reported by nine different agencies between 1990 and July 2000, for pesticides in surface water in California. Monitoring for α-endosulfan, β-endosulfan, and endosulfan sulfate was conducted between August 1990 and July 1996; no monitoring has been reported since 1996 (DPR, 2004). Table 16 summarizes these data. Table 16 shows that endosulfan sulfate has been detected more frequently in surface water samples than α- or β-endosulfan, and generally at higher concentrations.

Table 16. Summary of Historical Surface Water Sampling Data for Endosulfan in California Through July 2000

Chemical	No. of Analyses [a]	No. of Detections [a]	Detection Frequency (%) [a]	Concentration (µg/L) [b]		
				50th Percentile	75th Percentile	95th Percentile
α-Endosulfan	764	40	5.2	0.0025	0.005	0.05
β-Endosulfan	764	41	5.4	0.0025	0.036	0.05
Endosulfan Sulfate	661	114	17.2	0.005	0.029	0.05

[a] Adapted from Guo and Spurlock (2000), which summarizes water sampling conducted between August 1990 and July 2000. However, no monitoring for endosulfan has been reported since July 1996 (DPR, 2004), nor does the database differentiate between surface water systems that are sources of drinking water and those that are not (F. Spurlock, personal communication, June 7, 2005). The limit of quantification (LOQ) ranged from 0.00005 – 0.10 µg/L.

[b] Values are were calculated using the Percentile function in Excel, from data in DPR (2004). Calculated using ½ LOQ for samples <LOQ. Nine samples collected before introduction of permit conditions were omitted.

Exposure estimates were based on estimated total endosulfan concentrations, estimated as the sum of concentrations of α-endosulfan, β-endosulfan, and endosulfan sulfate. The sum of 95th percentiles reported in Table 16, 0.15 μg/L, was used in estimating short-term swimmer exposure. For long-term exposures, the median total endosulfan concentration of 0.01 μg/L was calculated from the 50th percentile concentrations in Table 16.

Endosulfan residues were detected in California surface waters in the Central Valley in 1991 through 1993, at concentrations up to 0.039 μg/L (Ross *et al.*, 1996; Ross *et al.*, 1999; Ross *et al.*, 2000); these detections are included in data summarized in Table 16. Water samples collected in 1997 from eight sites in Tulare County, some adjacent to cropland and others in the Sequoia National Park, contained α-endosulfan at concentrations ranging from 0.00009 – 0.0248 μg/L and β-endosulfan at concentrations ranging from 0.000041 – 0.1405 μg/L (LeNoir *et al*., 1999). Water samples collected from two lakes in the Sierra Nevada Mountains in 1997 contained α-endosulfan at concentrations ranging from 0.00030 – 0.0010 μg/L; β-endosulfan at concentrations ranging from 0.00017 – 0.0018 μg/L; and endosulfan sulfate at concentrations ranging from 0.00033 – 0.0029 μg/L (Fellers *et al.*, 2004). Although these results are not included in data reported in Table 16, they are within the range of those data.

Movement of endosulfan into surface water via rainfall runoff and irrigation drainage was documented in studies completed in the 1980s (Gonzalez *et al*., 1987; Fleck *et al*., 1991). Sampling of rainfall runoff from three treated fields in 1988 detected endosulfan in samples from all three fields, at concentrations ranging from 2.2 to 13 μg/L (Fleck *et al*., 1991). Irrigation drainage samples collected in October 1985 contained endosulfan at one of three sites (detection limit: 0.01 μg/L); the mean $\pm$ standard deviation concentration at that site was 0.014 $\pm$ 0.005 μg/L (Gonzalez *et al*., 1987).

In surface water systems, endosulfan residues have also been detected in sediment (Gonzalez *et al*., 1987; Fleck *et al.*, 1991; Ganapathy *et al.*, 1997; Weston *et al*., 2004); mussels (Singhasemanon, 1996; Ganapathy *et al.*, 1997); amphibians (Sparling *et al*., 2001); and fish (Singhasemanon, 1995; Brodberg and Pollock, 1999).

The detection of endosulfan residues in surface water, sediment, and aquatic organisms, and concerns about endosulfan's toxicity, led DPR, in 1991, to began requiring permit conditions to prevent use of endosulfan where it might be allowed to reach surface water (Okumura, 1991). Initially, these permit conditions were specific to nine counties (Colusa, Imperial, Monterey, Orange, San Joaquin, Santa Cruz, Stanislaus, and Ventura), but in 1992 they were expanded to cover the entire state (Okumura, 1992). Permit conditions specified that County Agricultural Commissioners were not to issue permits for endosulfan use "where runoff due to irrigation or rainfall from the treated area flows directly, or by way of drainage ditches or canals, into surface waters such as streams, rivers, lakes, lagoons, marshes, bays, estuaries, or the ocean."

No systematic monitoring of surface water has been performed to determine effectiveness of the permit conditions; however, several of the surface water samples containing detectable endosulfan occurred after the permit conditions were introduced. No endosulfan residues have been detected in drinking water in California in the past three years for which data are available (USDA, 2003; 2004; 2005). These results suggest that drinking water systems in California, and household water used for showering and bathing, are not likely to be a source of human exposure to endosulfan.

<u>Ground Water</u>

DPR has a well monitoring program that samples numerous wells each year to determine the presence and geographical distribution of agriculturally applied pesticides in groundwater. The program, including criteria for selection of wells and sampling and analytical methods, is described by Troiano *et al.* (2001). Between 1986 and 2003, a total of 2,758 well water samples collected in 48 California counties (out of 58 counties total) were tested for the presence of endosulfan and endosulfan sulfate (Schuette *et al*., 2003). Endosulfan was detected in ten samples, at concentrations ranging from 0.01 – 34.7 µg/L. All ten detections were classified as "unverified," because follow-up sampling failed to detect endosulfan or endosulfan sulfate. These results, along with reported non-detection of endosulfan residues in monitoring of drinking water systems (USDA, 2003; 2004; 2005), suggest that drinking water systems in California drawing from ground water are not likely to be a source of human exposure to endosulfan.

EXPOSURE ASSESSMENT

Exposure estimates are provided for representative exposure scenarios described in the Exposure Scenarios section, as well as for ambient air and bystander scenarios. For each scenario, estimates are provided for short-term (defined in this EAD as acute and up to one week), seasonal (intermediate-term intervals, lasting from one week to one year), annual, and lifetime exposures.

For short-term exposures, DPR estimates the highest exposure an individual may realistically experience during or following legal endosulfan uses. In order to estimate this "upper bound" of daily exposure, DPR generally uses the estimated population 95th percentile of daily exposure. A population estimate is used instead of a sample statistic because sample maxima and upper-end percentiles, in samples of the sizes usually available to exposure assessors, are both statistically unstable and known to underestimate the population values. The population estimate, on the other hand, is more stable because it is based on all the observations rather than a single value; moreover, it is adjusted, in effect, for sample size, correcting some of the underestimation bias due to small samples. A high percentile is estimated, rather than the maximum itself, because in theory, the maximum value of a lognormal population is infinitely large. In practice, exposures must be bounded because a finite amount of active ingredient (AI) is applied. The use of a high percentile acknowledges that the assumed lognormal distribution is probably not a perfect description of the population of exposures, especially at the upper extremes. The population 95^{th} is estimated, rather than a higher percentile, because the higher the percentile the less reliably it can be estimated and the more it tends to overestimate the population value (Chaisson *et al.*, 1999).

To estimate seasonal and annual exposures, the average daily exposure is of interest because over these periods of time, a worker is expected to encounter a range of daily exposures (i.e., DPR assumes that with increased exposure duration, repeated daily exposure at the upper-bound level is unlikely). To estimate the average, DPR uses the arithmetic mean of daily exposure (Powell, 2003). The arithmetic mean is used rather than the geometric mean or the median because, although it can be argued that the latter statistics better indicate the location of the center of a skewed distribution, it is not the center that is of interest in exposure assessment, but the expected magnitude of the exposure. While extremely high daily exposures are low-probability events, they do occur, and the arithmetic mean appropriately gives them weight in proportion to their probability. (In contrast, the geometric mean gives decreasing weight as the value of the exposure increases, and the median gives no weight whatsoever to extreme exposures.) In most instances, the mean daily exposure of individuals over time is not known. However, the mean daily exposure of a group of persons observed in a short-term study is believed to be the best available estimate of the mean for an individual over a longer period.

Handlers

Aerial, airblast and groundboom M/L/A were assumed to have exposures in the range of M/L and applicators (exposure estimates are normalized to an 8-hour day, and M/L/A would mix/load part of the day, and apply for the remainder). For this reason, separate M/L/A scenarios were not prepared for these scenarios.

Exposure Monitoring Studies

Exposure of handlers to endosulfan was monitored in three studies (Baugher, 1989; Lonsway *et al*., 1997; Hatzilarou *et al*., 2004). In the first study, exposure monitoring was conducted of M/L/As and applicators during airblast applications to pears and plums in California (Baugher, 1989). The airblast sprayers were pulled behind a tractor equipped with one of three cabs: a positive pressure, filtered, air-conditioned Nelson cab; a Case cab with windows open; or a cab with plastic dome windows and a canvas skirt. The workers wore long-sleeved cotton/polyester shirts and denim pants. During mixing/loading, the workers also wore aprons, chemical-resistant gloves and goggles, and half of the replicates applying with the Nelson cab used closed systems for mixing/loading. Passive dosimeters, consisting of patches as described by Durham and Wolfe (1962), were attached on the outside and inside of the clothing. Hand exposure was determined by sequential washes with soapy water and then water alone. Face and neck exposures were estimated from extrapolation of the residues on the chest and back dosimeters, respectively. The workers in the study handled 30-60 lbs (14-27 kg) of endosulfan, and application times ranged from 3.5 – 8.5 hrs. Passive dosimetry results averaged an exposure of 40.2 μg/lb AI handled for M/L/A using closed systems for mixing/loading and applying endosulfan in tractors with closed cabs; 55.4 μg/lb AI handled for M/L/A open-pour mixing/loading and applying endosulfan in tractors with closed cabs; and 671 μg/lb AI handled for M/L/A open-pour mixing/loading and applying endosulfan in tractors with open windows. Urinary monitoring for endosulfan diol was conducted for a period of 7 days. This metabolite was found above the limit of detection (0.001 mg/l) in the urine of only one worker, at a concentration of 0.0017 mg/l, and was considered by Baugher (1989) to be a false positive result because of the timing (14 days post-exposure). Therefore, this metabolite could not be used to derive an estimate of exposure. Because only three to six workers were monitored in the study under each set of conditions, there was insufficient replication to develop a reliable estimate of exposure. Results from this study were not used in estimating dermal exposure of handlers to endosulfan. U.S. EPA also found this study (submitted in two different reports) to be deficient and did not use it in their exposure assessment (U.S. EPA, 2002b).

Exposure of M/Ls and applicators to endosulfan during groundboom applications to tobacco was studied in Kentucky (Lonsway *et al.*, 1997). Two mixing/loading and five application events with endosulfan were monitored in this study. All activities were timed, and exposures were reported as mg AI/hr; total amounts of AI handled during each activity were not reported. Dermal exposure was estimated by assaying pesticide residues extracted from cotton gloves and gauze pads according to the method of Durham and Wolfe (1962). Inhalation exposure was estimated by assaying pesticide residues extracted from cartridges in personal air samplers. The M/Ls open-poured endosulfan into spray tanks. Mean M/L exposure to endosulfan was reported to be 135.3 mg/hr, of which 133.5 mg/hr (98.7%) was to the hands. Pesticide mixtures were applied with a ground boom tractor (no information was given about whether the tractor had a closed cab) or an open air highboy on 2.025-hectare (ha) test plots at a rate of 1 to 2 kg per ha. The total dermal exposure of applicators to endosulfan averaged 102.7 mg/hr. Hand exposure accounted for 39% (40.1 mg/hr) of this total, face and neck for 25% (25.4 mg/hr), chest for 18% (18.6 mg/hr), and back of the neck 13% (12.9 mg/hr). Endosulfan was not recovered from the respiratory cartridges (detection limit 0.25 ppm). Because amounts of endosulfan handled by each worker were not reported; mixing/loading was not done with a closed system (a closed system is required in California); insufficient information was given about applicator conditions (e.g., whether tractors had closed cabs); and because few replicates were monitored (two M/Ls and five applicators), results from this study could not be used to estimate worker exposure. U.S. EPA (2002b) apparently did not consider this study in their exposure assessment, nor was it mentioned in the RED (U.S. EPA, 2002b).

Hatzilazarou *et al.* (2004) monitored exposure to several pesticides, including endosulfan, using filter paper discs placed on the forehead and the chest of workers spraying pesticide solutions in a greenhouse. Pesticide solutions were applied to potted plants on benches until run-off, using a handheld sprayer with a 5-liter tank. The application rate for endosulfan was approximately 0.218 lbs AI/acre (0.317 kg AI/ha), although the amount of pesticide handled was not reported. Endosulfan residues were recovered from filter papers on both head and chest of the applicator, at 0.6 $\mu g/cm^2$ and 1.2 $\mu g/cm^2$, respectively. Pesticide concentrations in greenhouse air were determined at 2, 6, 12, 24, 72, and 144 hours post-application. Total endosulfan concentrations were highest during the first 2 hours post-application, at 10 $\mu g/m^3$. Between 2 and 12 hours, the average endosulfan concentration was 6 $\mu g/m^3$. Because the amount of pesticide handled was not reported, a single replicate was monitored, and only partial dermal exposure monitoring was done (head and chest only), this study could not be used to estimate worker exposure.

Exposure Estimates Using Surrogate and Generic Data

Although no acceptable studies were available in which handler exposure to endosulfan was monitored, one acceptable study was submitted in which dermal and inhalation exposure of airblast applicators to the surrogate compound, carbaryl, was monitored (Smith, 2005). This study provided acceptable data for estimating exposure of airblast applicators driving open-cab tractors. Carbaryl was applied in three orchard crops (peaches, apples, and citrus) in three states (Georgia, Idaho, and Florida). Applicators wore either Sou'wester rain hats (15 replicates) or hooded rain jackets (10 replicates) as chemical-resistant headgear; because the jackets provided an extra layer of clothing over the torso and arms, only data from the replicates wearing rain hats were used to estimate exposure. Dermal exposure was monitored with whole-body dosimeters, face/neck wipes, hand washes and patches on the inside and outside of headgear. Inhalation exposure was monitored with breathing zone air samplers consisting of OSHA Versatile Sampler tubes, each containing glass fiber filter and XAD-2 sorbent and connected to a sampler pump calibrated to 2 liters per minute. Applicators were monitored for 5 – 8 hours each, which is about the length of a typical workday for them. Actual spray times ranged 3.3 – 5.7 hours; applicators handled 24 – 90 pounds AI (11 – 41 kg), and treated 12 – 30 acres (5 – 12 ha). Quality assurance samples consisted of laboratory control samples of each matrix, laboratory-fortified samples of each matrix, and field fortified samples of each matrix. Field fortifications (FFs) consisted of each sample matrix spiked with formulated product, and with the exception of socks all FF recoveries were in the acceptable range (70 – 120%). Results were corrected for FF recoveries below 90%.

Exposure monitoring results for airblast applicators wearing Sou'wester rain hats are summarized in Table 17. Airblast applicators are required to wear chemical-resistant headgear, as product labels require chemical-resistant headgear for overhead exposures such as occur during airblast application.

Table 17. Exposure of Open-Cab Airblast Applicators [a]

	Exposure Rate (µg AI/lb handled)
Dermal Exposure	
Arithmetic Mean	70.2
Standard Deviation	65.4
95th Percentile [b]	276
Inhalation Exposure	
Arithmetic Mean	3.41
Standard Deviation	3.65
95th Percentile [b]	9.54

[a] Summary of data from open-cab airblast exposure monitoring study (Smith, 2005). Only the 15 replicates wearing Sou'wester rain hats were included; product labels require chemical-resistant headgear for overhead exposures such as occur during airblast application. Arithmetic mean exposure rates were used to calculate long-term exposures and 95th percentile exposure rates were used to calculate short-term exposures. All estimates were rounded to three significant figures.

[b] 95th percentile estimates calculated in Excel, assuming a lognormal distribution. First the natural logarithm (ln) was calculated for each value using the LN function; arithmetic mean and standard deviation was then calculated for the natural logarithms (am(lns) and asd(lns), respectively). The NORMSINV function, with a probability of 0.95, was used to get the inverse of the standard normal cumulative distribution, which was multiplied by asd(lns). This result was added to am(lns), and the sum taken as the power of e with the EXP function.

With the exception of airblast applicators and handlers dipping nursery stock (discussed later in this section), exposure estimates were derived using the Pesticide Handler Exposure Database, or PHED (1995). PHED was developed by the U.S. EPA, Health Canada and the American Crop Protection Association to provide non-chemical-specific (generic) pesticide handler exposure estimates for specific handler scenarios. It combines exposure data from multiple field monitoring studies of different AIs. The user selects a subset of the data having the same or a similar application method and formulation type as the target scenario. The use of non-chemical-specific exposure estimates is based on two assumptions, that exposure is primarily a function of the pesticide application method/equipment and formulation type rather than the physical-chemical properties of the specific AI, and that exposure is proportional to the amount of AI handled (Reinert *et al.*, 1986; Versar, 1992). These assumptions are supported by comparisons of exposure across several studies (Rutz and Krieger, 1992; van Hemmen, 1992).

PHED has limitations as a generic database (Powell, 2002). It combines measurements from diverse studies involving different protocols, analytical methods and residue detection limits. Most dermal exposure studies in PHED use the patch dosimetry method of Durham and Wolfe (1962); residues on patches placed on different parts of the body are multiplied by the surface area of the body part to estimate its exposure. These partial estimates are then summed to provide a total body exposure estimate. Some studies observed exposure only to selected body parts such as the hands, arms and face. As a consequence, dermal exposure estimates for different body parts may be based on data from different studies. Further, for some handler scenarios, the number of matching observations in the PHED is so small that the possibility they do not represent the target scenario is substantial. Due to the degree of uncertainty introduced by PHED, DPR calculates upper confidence limits on the exposure statistics to increase the confidence in the estimates of exposure.

When using PHED to estimate short-term exposure, DPR uses the 90% upper confidence limit (UCL) on the 95th percentile. The UCL is used to account for some of the uncertainty inherent in using surrogate data and to increase the confidence that exposures are not underestimated. (Confidence limits on percentiles, also called tolerance limits, are described by Hahn and Meeker (1991).) Estimating the confidence limit requires knowing the mean and standard deviation. PHED reports the mean of total dermal exposure, but only the coefficients of variation for separate body regions. Because the sample sizes per body region differ and because the correlations among body regions are unknown, the standard deviation of total dermal exposure cannot be calculated. In order to approximate the confidence limit for the 95th percentile, DPR makes the assumption that total exposure is lognormally distributed across persons and has a coefficient of variation of 100 percent. The approximation (Powell, 2002) uses the fact that in any lognormal distribution with a given coefficient of variation, the confidence limit for the 95th percentile is a constant multiple of the arithmetic mean. The value of the multiplier depends only on sample size. To use the approximation with PHED data, the multiplier corresponding to the sample size is used (for dermal exposure, the median number of observations over body regions is used). If the sample size is between 20 and 119, the multiplier is 4; if it is between 12 and 19, the multiplier is 5 (Powell, 2002).

When using surrogate data to estimate seasonal or annual exposure, DPR uses the 90% UCL on the arithmetic mean. The 90% UCL is used for the reasons listed in the previous paragraph. As with short-term exposure estimates based on PHED subsets, a multiplier corresponding to the median sample size over body regions is used. If the median sample size is greater than 15, the multiplier is 1 (Powell, 2002).

Handlers of endosulfan are required to wear protective clothing and PPE, as described in the Label Precautions and California Requirements section. Clothing and PPE have been shown to reduce exposure to pesticides (Thongsinthusak *et al.*, 1991), and default protection factors are used by DPR to adjust exposure estimates. For M/Ls, exposure estimates were provided for WP in both WSP and non-WSP packaging. U.S. EPA (2002a) would require all WP to be packaged in WSP, and non-WSP packaging is being phased out. However, as of March 2007, non-WSP products were available in California.

Surrogate data from the PUR also were used to estimate intervals for seasonal and annual exposures. Endosulfan is registered for use on several different crops, and for many crops repeated use is allowed within a growing season, suggesting that handlers may potentially be exposed throughout the year. Repeated exposures are especially likely for professional applicators and their employees, as these handlers can make the same treatment for several growers. However, PUR data show that in many parts of the state and in many crops endosulfan use does not occur throughout the year, and that at other times relatively few applications are made. It is reasonable to assume that an individual handler is less likely to be exposed to endosulfan during these relatively low-use intervals. Thus, rather than assume that handlers are exposed throughout the year, annual use patterns are plotted based on monthly PUR data from one or more counties with the highest use. Annual exposure to endosulfan is assumed to be limited to the months when use is relatively high (defined as 5% or more of annual use each month).

U.S. EPA (2002b) assumed that handler exposure durations would only be one day to one month. The basis for this assumption was not explained.

Aerial applications

The maximum application rate for endosulfan applied aerially is on nut crops, 2.5 lb/acre (2.8 kg AI/ha). The number of acres treated per day was assumed to be 350 acres/day (142 ha/day), based on the default recommended by U.S. EPA (2001). Exposure estimates for handlers involved in aerial applications assumed that M/Ls and flaggers wear the clothing specified on product labels: long-sleeved shirt and pants, waterproof or chemical-resistant gloves, and shoes and socks (see Appendices 3-6). Applicators (pilots) are not required to wear gloves during an application (3 CCR 6738), and were assumed to wear all of the required clothing and PPE except gloves (see Appendix 6). Open cockpits were assumed for pilots, as there is no requirement for closed cockpits during applications.

Assumptions used in exposure calculations, results of PHED subsets, and short-term handler exposure estimates for workers handling endosulfan in support of aerial applications are given in Table 18. Combined short-term absorbed daily dosage (STADD) estimates for M/Ls range 0.185 – 2.63 mg/kg/day, for M/Ls handling EC and WP formulations (Table 18). STADD are 0.790 mg/kg/day and 0.373 mg/kg/day for aerial applicators and flaggers, respectively.

Table 18. Exposure Rates Calculated from Surrogate Data and Short-Term Exposure Estimates for Workers Handling Endosulfan in Support of Aerial Applications [a]

Scenario	# [b]	Short-Term Exposure Rates [c] (µg/lb AI handled)		Long-Term Exposure Rates [d] (µg/lb AI handled)		STADD [e] (mg/kg/day)		
		Dermal	Inhalation	Dermal	Inhalation	Dermal	Inhalation	Total
Aerial [f]								
M/L EC	3	37.0	0.512	9.24	0.128	0.219	0.006	0.225
M/L WP [g]	4	392	24.7	98.0	4.94	2.32	0.309	2.63
M/L WP/WSP	5	28.4	1.38	11.3	0.554	0.168	0.017	0.185
Applicator	6	133	0.286	44.3	0.115	0.786	0.004	0.790
Flagger	7	62.8	0.080	16.0	0.020	0.371	0.002	0.373
High-Acre Aerial [h]								
M/L EC	3	37.0	0.512	9.24	0.128	0.450	0.013	0.463
M/L WP [g]	4	392	24.7	98.0	4.94	4.77	0.635	5.40
M/L WP/WSP	5	28.4	1.38	11.3	0.554	0.345	0.036	0.381
Applicator	6	133	0.286	44.3	0.115	1.62	0.007	1.63

[a] All scenarios except airblast applicator were based on data from the Pesticide Handlers Exposure Database (PHED, 1995). Airblast applicator exposure based on data from Smith (2005), shown in Table 17. Exposure rates and exposure estimates were rounded to three significant figures. Abbreviations: EC = emulsifiable concentrate. GB = groundboom. M/L = mixer/loader. WP = wettable powder. WSP = water soluble packaging.

[b] Appendix number with details from PHED. Handlers were assumed to wear gloves as specified on product labels, except aerial applicators (exempt from wearing gloves under California law); respirator (except M/L using a closed system); and coveralls. M/L assumed to wear chemical-resistant apron. Protection factors given in appendices.

[c] These exposure rates were used to calculate STADD, as explained in Footnote [e].

[d] These exposure rates were used to calculate Seasonal Average Daily Dosage and Annual Average Daily Dosage in Table 19.

[e] Short-Term Absorbed Daily Dosage (STADD) is an upper-bound estimate calculated from the short-term exposure. Application rate is maximum rate on product labels, which varied for each scenario; acres treated per day varies by scenario. Estimates were rounded to three significant figures. Calculation:
STADD = [(short-term exposure) x (absorption) x (acres treated/day) x (application rate)]/(70 kg body weight).
Calculation assumptions include: Dermal absorption = 47.3% (Craine, 1988) ; Body weight = 70 kg (Thongsinthusak *et al*., 1993); Inhalation rate 16.7 L/min (Andrews and Patterson, 2000); Inhalation absorption = 100%.

[f] STADD estimates assumed 350 acres (142 ha) treated/day (U.S.EPA, 2001), and a maximum application rate of 2.5 lbs AI/acre (2.8 kg AI/ha), maximum rate on tree nuts.

[g] Data from open pouring mixing/loading used in exposure estimate. U.S. EPA (2002a) would require all WP to be packaged in WSP, and non-WSP packaging is being phased out.

[h] STADD estimates assumed 1,200 acres (486 ha) treated/day (U.S. EPA, 2001), and a maximum application rate of 1.5 lbs AI/acre (1.7 kg AI/ha), maximum rate on cotton. Multiple flaggers assumed for large-acre applications (U.S. EPA, 2001), and high-acre scenarios include only M/L and applicator.

Exposures were also estimated for high-acre applications of endosulfan to field crops such as cotton and corn. The maximum application rate for endosulfan applied to cotton is 1.5 lb/acre (1.7 kg AI/ha). The number of acres treated per day was assumed to be 1,200 acres/day (486 ha/day), based on the default recommended by U.S. EPA (2001).

Multiple flaggers were assumed to participate large-acre applications, and these scenarios include estimates only for M/L and applicator scenarios (U.S. EPA, 2001).

Seasonal, annual, and lifetime exposure estimates for occupational handlers of endosulfan in support of aerial applications are summarized in Table 19. As in Table 18, additional estimates are given in Table 19 for large-acre applications to field crops such as cotton.

Table 19. Seasonal, Annual, and Lifetime Estimates for Workers Handling Endosulfan in Support of Aerial Applications

Scenario [a]	SADD [b] (mg/kg/day)			AADD [c] (mg/kg/day)			LADD [d] (mg/kg/day)		
	Dermal	Inhalation	Total	Dermal	Inhalation	Total	Dermal	Inhalation	Total
Aerial [e]									
M/L EC	0.033	0.001	0.034	0.011	0.0003	0.011	0.006	0.0002	0.006
M/L WP [f]	0.348	0.037	0.385	0.116	0.012	0.128	0.062	0.007	0.069
M/L WSP	0.040	0.004	0.044	0.014	0.001	0.015	0.007	0.001	0.008
Applicator	0.157	0.001	0.158	0.053	0.0003	0.053	0.028	0.0002	0.028
Flagger	0.057	0.0002	0.057	0.019	0.00005	0.019	0.010	0.00003	0.010
High-Acre Aerial [g]									
M/L EC	0.112	0.004	0.116	0.028	0.0008	0.029	0.015	0.0004	0.015
M/L WP [f]	1.19	0.127	1.32	0.298	0.032	0.330	0.159	0.017	0.176
M/L WSP	0.138	0.014	0.152	0.034	0.004	0.038	0.018	0.002	0.020
Applicator	0.539	0.003	0.542	0.135	0.00007	0.135	0.072	0.0004	0.072

[a] Abbreviations: EC = emulsifiable concentrate. GB = groundboom. M/L = mixer/loader. WP = wettable powder. WSP = water soluble packaging containing wettable powder.

[b] Seasonal Average Daily Dosage is a 90% upper confidence estimate calculated from the long-term exposure rates given in Table 18. Dermal absorption: 47.3% (Craine, 1988). Inhalation absorption assumed to be 100%. Body weight assumed to be 70 kg (Thongsinthusak *et al*., 1993). Calculation:
SADD = [(long-term exposure) x (absorption) x (acres treated/day) x (application rate)]/(70 kg body weight).

[c] Annual Average Daily Dosage = SADD x (annual use months per year)/(12 months in a year).

[d] Lifetime Average Daily Dosage = AADD x (40 years of work in a lifetime)/(75 years in a lifetime).

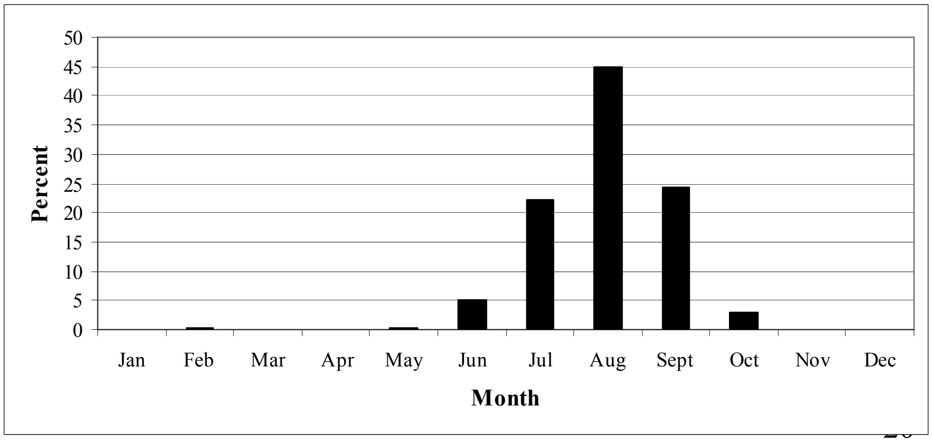
[e] Exposure estimates assumed 350 acres (142 ha) treated/day (U.S. EPA, 2001), and an application rate of 1.5 lbs AI/acre (1.7 kg AI/ha), maximum rate on collards, cotton, grapes, lettuce, sweet corn and tomatoes. Annual exposure estimate based on high-use period of 4 months, based on data from DPR (2006a).

[f] Data from open pour mixing/loading used in exposure estimate. U.S. EPA (2002a) would require all WP to be packaged in WSP, and non-WSP packaging is being phased out.

[g] Exposure estimates assumed 1,200 acres (486 ha) treated/day (U.S. EPA, 2001), and a maximum application rate of 1.5 lb AI/acre (1.7 kg AI/ha), maximum rate on cotton. Annual exposure estimate based on high-use period of 3 months.

To estimate seasonal and annual exposures of workers involved in aerial applications of endosulfan, temporal patterns were investigated by plotting percent of annual use in Fresno County, which has the most aerial applications of endosulfan. Although the maximum application rate for endosulfan is on tree nuts and fruits (2.5 lbs AI/acre, or 2.8 kg AI/ha), PUR data show that endosulfan has rarely been applied to these crops aerially (DPR, 2006a; data not shown). Because of this, aerial endosulfan use was determined for crops where the maximum application rate is 1.5 lbs AI/acre (1.7 kg AI/ha), including cotton, grapes, and sweet corn; these data are summarized in Figure 5. The majority of annual use occurred between June and September; these four months include about 96% of annual applications. Annual exposure was estimated to occur during these four months.

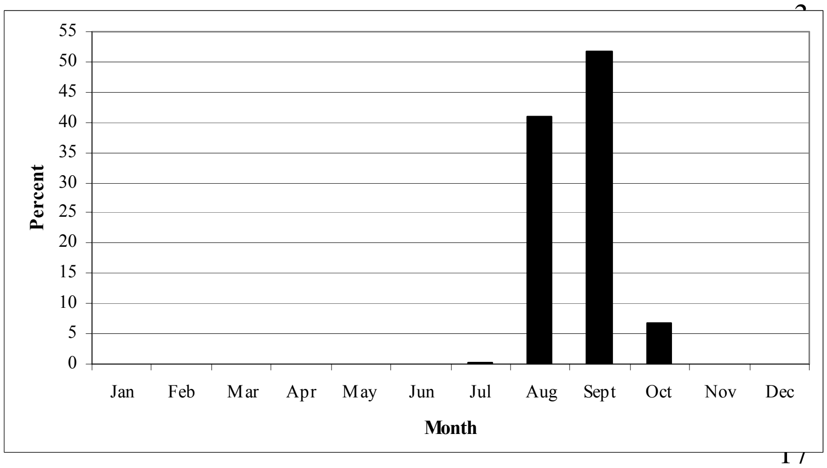
Figure 5. Aerial Applications of Endosulfan in Fresno County, 2000 – 2004 [a]



[a] Percent calculations based on pounds applied aerially to cotton, grapes, and sweet corn in Fresno County (DPR, 2006a; queried January 26, 2006).

To estimate seasonal and annual exposures of handlers involved in high-acre aerial applications, percent of annual use each month on cotton in Kern and Kings counties was plotted (Figure 6). Only applications exceeding 350 acres each were included in Figure 6; more of these high-acre applications occurred in Kern and Kings counties than in Fresno County. When limited to applications exceeding 350 acres, the majority of annual endosulfan use occurred between August and October; these three months include nearly 100% of annual use. Annual exposure related to large-acre applications was estimated to occur during these three months.

Figure 6. High-Acre Aerial Applications of Endosulfan to Cotton in Kern and Kings Counties, 2000 – 2004 [a]



[a] Percent calculations based on pounds applied aerially to cotton (DPR, 2006a; queried July 30, 2007).

Airblast applications

Table 20 summarizes PHED data used in M/L exposure estimates and STADD for handlers in support of applications of endosulfan using ground equipment, including airblast sprayers. Airblast applicator exposure estimates are based on a recent exposure monitoring study (Smith, 2005). The maximum application rate for endosulfan applied with airblast is on nut crops and tree fruits, 2.5 lb/acre (2.8 kg AI/ha). For airblast applications, the amount treated was assumed to be 40 acres/day (16 ha/day), the default recommended by U.S. EPA (2001). Exposure estimates for handlers involved in airblast applications assumed that all handlers wear the clothing and PPE specified on product labels (product labels require chemical-resistant headgear for overhead exposures such as occur during airblast application). Open cabs were assumed for applicators, as there is no requirement for closed cabs during applications. STADD for M/Ls range 0.021 – 0.300 mg/kg/day. The applicator STADD is 0.188 mg/kg/day.

Use data from Los Angeles County, which has the most ground applications of endosulfan to tree fruits (including pome and stone fruits), are summarized in Figure 7. The majority of annual use (95%) occurred in two months, April and May (Figure 7). Annual exposure was estimated to occur during these two months. Seasonal, annual, and lifetime exposure estimates are summarized in Table 21.

Table 20. Exposure Rates Calculated from Surrogate Data and Short-Term Exposure Estimates for Workers Handling Endosulfan in Support of Ground Applications [a]

Scenario	# [b]	Short-Term Exposure Rates [c] (µg/lb AI handled)		Long-Term Exposure Rates [d] (µg/lb AI handled)		STADD [e] (mg/kg/day)		
		Dermal	Inhalation	Dermal	Inhalation	Dermal	Inhalation	Total
Airblast [f]								
M/L EC	3	37.0	0.512	9.24	0.128	0.025	0.001	0.026
M/L WP [g]	4	392	24.7	98.0	4.94	0.265	0.035	0.300
M/L WSP	5	28.4	1.38	11.3	0.554	0.019	0.002	0.021
Applicator	- -	276	9.54	70.2	3.41	0.187	0.001	0.188
GB [h]								
M/L EC	3	37.0	0.512	9.24	0.128	0.040	0.001	0.041
M/L WP [g]	4	392	24.7	98.0	4.94	0.424	0.056	0.480
M/L WSP	5	28.4	1.38	11.3	0.554	0.031	0.003	0.034
Applicator	8	40.6	0.472	6.04	0.118	0.044	0.001	0.045
High-Acre GB [i]								
M/L EC	3	37.0	0.512	9.24	0.128	0.075	0.002	0.077
M/L WP [g]	4	392	24.7	98.0	4.94	0.795	0.105	0.900
M/L WSP	5	28.4	1.38	11.3	0.554	0.058	0.006	0.064
Applicator	8	40.6	0.472	6.04	0.118	0.082	0.002	0.084

[a] All scenarios except airblast applicator were based on data from the Pesticide Handlers Exposure Database (PHED, 1995). Airblast applicator exposure based on data from Smith (2005), shown in Table 17. Exposure rates and exposure estimates were rounded to three significant figures. Abbreviations: EC = emulsifiable concentrate. GB = groundboom. M/L = mixer/loader. WP = wettable powder. WSP = water soluble packaging.

[b] Appendix number with details from PHED. Handlers were assumed to wear gloves as specified on product labels, except aerial applicators (exempt from wearing gloves under California law); respirator (except M/L using a closed system); and coveralls. M/L assumed to wear chemical-resistant apron. Protection factors given in appendices.

[c] These exposure rates were used to calculate STADD, as explained in Footnote [e].

[d] These exposure rates were used to calculate Seasonal Average Daily Dosage and Annual Average Daily Dosage in Table 19.

[e] Short-Term Absorbed Daily Dosage (STADD) is an upper-bound estimate calculated from the short-term exposure. Application rate is maximum rate on product labels, which varied for each scenario; acres treated per day varies by scenario. Estimates were rounded to three significant figures. Calculation:

STADD = [(short-term exposure) x (absorption) x (acres treated/day) x (application rate)]/(70 kg body weight).

Calculation assumptions include: Dermal absorption = 47.3% (Craine, 1988) ; Body weight = 70 kg (Thongsinthusak *et al*., 1993); Inhalation rate 16.7 L/min (Andrews and Patterson, 2000); Inhalation absorption = 100%.

[f] STADD estimates assumed 40 acres (16 ha) treated/day (U.S. EPA, 2001), and a maximum application rate of 2.5 lbs AI/acre (2.8 kg AI/ha), maximum rate on tree nuts.

[g] Data from open pouring mixing/loading used in exposure estimate. U.S. EPA (2002a) would require all WP to be packaged in WSP, and non-WSP packaging is being phased out.

[h] STADD estimates assumed 80 acres (32 ha) treated/day (U.S. EPA, 2001), and a maximum application rate of 2.0 lb AI/acre (2.2 kg AI/ha), maximum rate on strawberry, pineapple, or crucifers for seed only.

[i] STADD estimates assumed 200 acres (81 ha) treated/day (U.S. EPA, 2001), and a maximum application rate of 1.5 lb AI/acre (1.7 kg AI/ha), maximum rate on cotton.

Table 21. Seasonal, Annual, and Lifetime Estimates for Workers Handling Endosulfan in Support of Ground Applications

Scenario [a]	SADD [b] (mg/kg/day)			AADD [c] (mg/kg/day)			LADD [d] (mg/kg/day)		
	Dermal	Inhalation	Total	Dermal	Inhalation	Total	Dermal	Inhalation	Total
Airblast [g]									
M/L EC	0.006	0.0002	0.006	0.001	0.00003	0.001	0.0006	0.00004	0.0006
M/L WP [f]	0.066	0.007	0.073	0.011	0.001	0.012	0.006	0.001	0.007
M/L WSP	0.007	0.001	0.008	0.001	0.0001	0.001	0.0007	0.0001	0.0008
Applicator	0.047	0.0005	0.048	0.008	0.00008	0.008	0.004	0.00004	0.004
GB [h]									
M/L EC	0.008	0.0002	0.008	0.003	0.0001	0.003	0.001	0.00004	0.001
M/L WP [f]	0.080	0.008	0.088	0.033	0.004	0.037	0.018	0.002	0.020
M/L WSP	0.009	0.001	0.010	0.004	0.0004	0.004	0.002	0.0002	0.002
Applicator	0.047	0.0005	0.048	0.008	0.00008	0.008	0.004	0.00004	0.004

[a] Abbreviations: EC = emulsifiable concentrate. GB = groundboom. M/L = mixer/loader. WP = wettable powder. WSP = water soluble packaging containing wettable powder.

[b] Seasonal Average Daily Dosage is a 90% upper confidence estimate calculated from the long-term exposure rates given in Table 18. Dermal absorption: 47.3% (Craine, 1988). Inhalation absorption assumed to be 100%. Body weight assumed to be 70 kg (Thongsinthusak *et al*., 1993). Calculation:

SADD = [(long-term exposure) x (absorption) x (acres treated/day) x (application rate)]/(70 kg body weight).

[c] Annual Average Daily Dosage = SADD x (annual use months per year)/(12 months in a year).

[d] Lifetime Average Daily Dosage = AADD x (40 years of work in a lifetime)/(75 years in a lifetime).

[e] Exposure estimates assumed 350 acres (142 ha) treated/day (U.S. EPA, 2001), and an application rate of 1.5 lbs AI/acre (1.7 kg AI/ha), maximum rate on collards, cotton, grapes, lettuce, sweet corn and tomatoes. Annual exposure estimate based on high-use period of 4 months, based on data from DPR (2006a).

[f] Data from open pour mixing/loading used in exposure estimate. U.S. EPA (2002a) would require all WP to be packaged in WSP, and non-WSP packaging is being phased out.

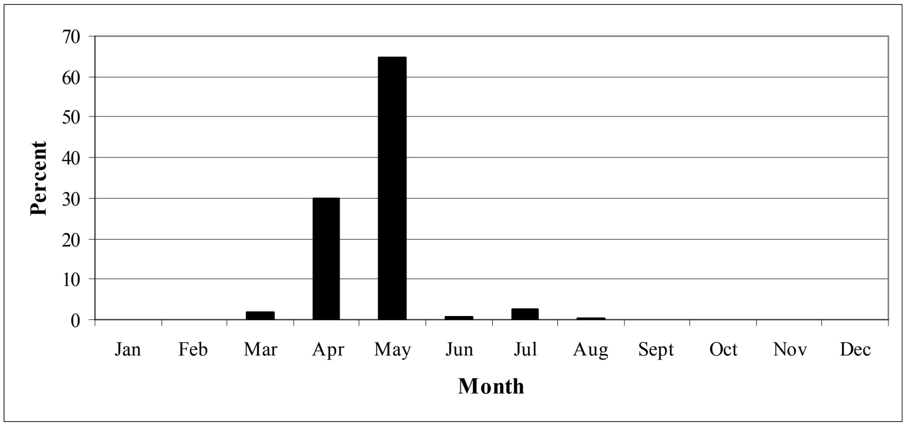
[g] Exposure estimates assumed 40 acres (16 ha) treated/day (U.S. EPA, 2001), and a maximum application rate of 2.5 lbs AI/acre (2.8 kg AI/ha), maximum rate on tree fruits. Annual exposure estimate based on high-use period of 2 months.

[h] Exposure estimates assumed 80 acres (32 ha) treated/day (U.S. EPA, 2001), and a maximum application rate of 1.5 lb AI/acre (1.7 kg AI/ha), maximum rate on cotton. Annual exposure estimate based on high-use period of 5 months.

Groundboom Applications

The maximum application rate for endosulfan applied via groundboom is 2.0 lb AI/acre (2.2 kg AI/ha), applied to strawberry, pineapple, or crucifers for seed only. For groundboom applications, the amount treated was assumed to be 80 acres/day (32 ha/day), which is the default used by DPR (U.S. EPA, 2001). In addition, high-acre applications to field crops such as cotton were assumed to treat 200 acres/day (81 ha/day).

Figure 7. Airblast applications of Endosulfan in Los Angeles County, 2000 – 2004 [a]



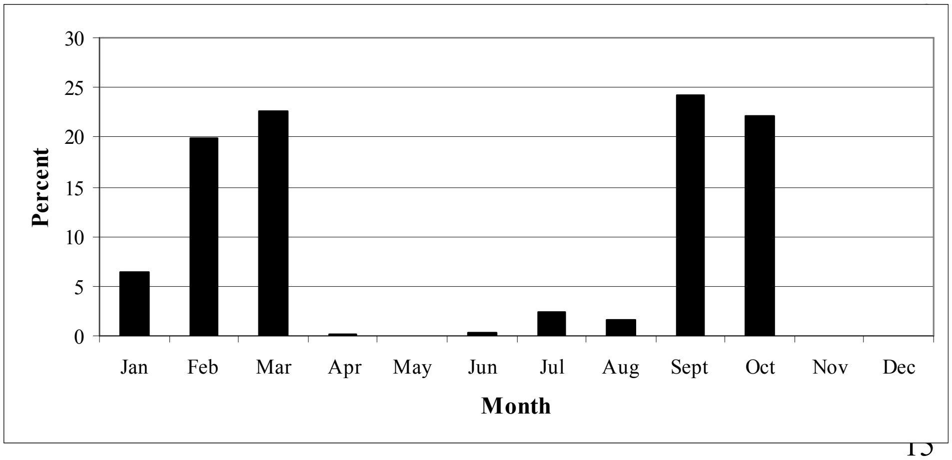
[a] Percent calculations based on pounds applied by ground methods to tree fruits in Los Angeles County (DPR, 2006a; queried January 26, 2006).

Exposure estimates for handlers involved in groundboom applications assumed a closed system for the M/L and that all handlers wear the clothing and PPE specified on the product label: long-sleeved shirt and pants, waterproof gloves, shoes and socks, and respirator. Open cabs were assumed for applicators, as there is no requirement for closed cabs during applications. STADD for M/Ls range 0.041 – 0.480 mg/kg/day. The applicator STADD is 0.045 mg/kg/day (Table 20).

Although the maximum application rate for groundboom is on strawberry or pineapple, examination of PUR data shows that endosulfan has infrequently been applied to these crops (DPR, 2006a; data not shown). Because of this, ground applications of endosulfan to sweet corn, collards, cotton, and lettuce, where the maximum application rate is 1.5 lbs AI/acre (1.7 kg AI/ha), were used instead for seasonal and annual exposure estimates. Use data for endosulfan on these crops in Fresno County, where the highest use on these crops was reported, are summarized in Figure 8.

The majority of annual use occurred in two intervals, January – March, and September – October; these five months accounted for approximately 95% of annual applications (Figure 8). Annual exposure was estimated to occur during these five months. Seasonal, annual and lifetime exposure estimates for handlers of endosulfan in support of groundboom applications are given in Table 21.

Figure 8. Groundboom applications of Endosulfan in Fresno County, 2000 – 2004 [a]



[a] Percent calculations based on pounds applied by ground methods to sweet corn, collards, cotton, and lettuce in Fresno County (DPR, 2006a; queried January 26, 2006).

Examination of PUR data shows that ground applications of endosulfan to cotton are infrequent. Therefore, seasonal, annual and lifetime exposures to endosulfan associated with high-acre applications by groundboom are not anticipated, and are not included in Table 21.

<u>Backpack Applications</u>

Table 22 summarizes PHED data and assumptions used in exposure estimates and STADD for handlers applying endosulfan with handheld equipment, including backpack sprayers. In its exposure scenarios for M/L/As using backpack sprayers, U.S. EPA (2002a) assessed use on three crops, greenhouse tomatoes, tobacco, and cherries. In California, the highest exposure estimates are associated with applications to macadamia nuts, where the maximum rate is 1 lb AI/100 gallons. Assuming that workers apply 40 gallons/day (U.S. EPA, 2001), the total amount handled is 0.4 lb AI/day (0.18 kg AI/day). The STADD is 0.043 mg/kg/day.

Table 22. Data Used and Short-Term Exposure Estimates for Handlers Using Handheld Equipment to Apply Endosulfan

Scenario [a]	# [b]	Short-term Exposure [c] (µg/lb AI handled)		Long-term Exposure [c] (µg/lb AI handled)		STADD [d] (mg/kg/day)		
		Dermal	Inhalation	Dermal	Inhalation	Dermal	Inhalation	Total
BP [e]								
M/L/A EC	9	16,000	10.5	5,320	3.50	0.043	0.0001	0.043
HPHW [f]								
M/L/A EC	10	7,400	75.5	2,960	30.2	0.501	0.010	0.511
LPHW [e]								
M/L/A EC	11	4,720	13.7	1,570	4.56	0.013	0.0001	0.013
M/L/A WP	12	35,800	520	7,160	104	0.097	0.003	0.100
Dip [g]								
M/L EC	3	37.0	0.512	- -	- -	0.00003	0.000001	0.00003
M/L WP	4	392	24.7	- -	- -	0.0003	0.00004	0.003
Applicator	13/14	- -	- -	- -	- -	41.4	0.005	41.4

[a] Abbreviations: BP = backpack sprayer. EC = emulsifiable concentrate. HPHW = high pressure handwand. LPHW = low pressure handwand. M/L = mixer/loader. M/L/A = mixer/loader/applicator. WP = wettable powder.

[b] Appendix number containing data and assumptions used in calculations. Handlers were assumed to wear gloves, respirator, and coveralls, as specified on product labels. Protection factors given in appendices.

[c] Dermal and inhalation exposure calculated from surrogate data using the Pesticide Handlers Exposure Database (PHED) database and software (PHED, 1995). Values from PHED were rounded to three significant figures.

[d] Short-Term Absorbed Daily Dosage (STADD) is an upper-bound estimate calculated from the short-term exposure. Application rate is maximum rate on product labels, which varied for each scenario; acres treated per day varies by scenario. Estimates were rounded to three significant figures. Calculation:

STADD = [(short-term exposure) x (absorption) x (acres treated/day) x (application rate)]/(70 kg body weight).

Calculation assumptions include: Dermal absorption = 47.3% (Craine, 1988); Body weight = 70 kg (Thongsinthusak, *et al*., 1993); Inhalation rate 16.7 L/min (Andrews and Patterson, 2000); Inhalation absorption = 100%.

[e] STADD estimates assumed handling of 40 gal/day (150 l/day; US EPA, 2001), containing 1.0 lb AI/100 gal (0.12 kg AI/100 l; maximum application for macadamia nuts), for a total of 0.4 lb AI/day (0.2 kg AI/day).

[f] STADD estimates assumed handling of 1,000 gal/day (3,800 l/day; US EPA, 2001), containing 1.0 lb AI/100 gal (0.12 kg AI/100 l; maximum application for macadamia nuts), for a total of 10 lb AI/day (4.5 kg AI/day).

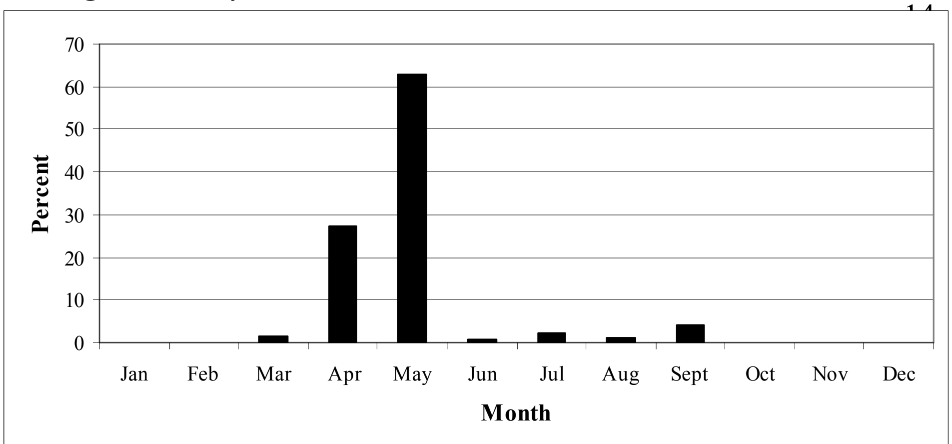
[g] STADD estimates assumed handling of 40 gal/day, containing 1.25 lb AI/40 gal (0.15 kg AI/40 l), for a total of 1.25 lb AI/day (0.56 kg AI/day). M/L estimates from PHED. Applicator dermal exposure estimates based on RAGS-E equations (U.S. EPA, 2004a). Applicator inhalation exposure estimates based on SWIMODEL (U.S. EPA, 2003), assuming a saturated endosulfan vapor concentration. See Appendix 13 and Appendix 14 for calculations of applicator exposure estimates.

Although the highest use rate for backpack sprayers is on macadamia nuts, examination of PUR data shows that endosulfan has infrequently been applied to this crop (DPR, 2006a; data not shown). Because of this, ground applications of endosulfan to apricots, nectarines, peaches, and pecans, where the maximum application rate is 0.75 lbs AI/100 gallons, were used instead for seasonal and annual exposure estimates. Assuming that workers apply 40 gallons/day (U.S. EPA, 2001), the total amount handled is 0.3 lb AI/day (0.14 kg AI/day).

To estimate seasonal and annual exposures of M/L/As applying endosulfan with backpack sprayers, the average percent of annual use each month was plotted for the five-year interval 2000 – 2004. Figure 9 summarizes ground applications of endosulfan to apricots, nectarines, peaches, and pecans in Los Angeles County. For this estimate, all ground applications were assumed to have been made by backpack sprayers.

Figure 9 shows that about 90% of use occurred in April and May. Annual exposure was estimated to occur during these two months. Table 23 contains seasonal, annual, and lifetime exposure estimates for M/L/A scenarios.

Figure 9. Ground Applications of Endosulfan to Apricots, Nectarines, Peaches and Pecans in Los Angeles County, 2000 – 2004 [a]



[a] Percent calculations based on pounds applied by ground methods (DPR, 2006a; queried January 26, 2006).

<u>High Pressure Handwand Applications</u>

High pressure handwands can be used to apply endosulfan to the same crops as backpack sprayers. Exposure was estimated for this scenario using the same assumptions as for the backpack sprayer, except that greater amounts are typically handled with high pressure handwands. Assuming that workers apply 1,000 gallons/day (U.S. EPA, 2001), the total amount handled is 10 lb AI/day (4.5 kg AI/day). The STADD is 0.511 mg/kg/day (Table 22). Annual exposure was estimated to occur during the two months shown in Figure 9; seasonal, annual, and lifetime exposure estimates are summarized in Table 23.

<u>Low Pressure Handwand Applications</u>

Low pressure handwands can be used to apply EC endosulfan products to the same crops as backpack sprayers. Exposures were estimated using the same assumptions as for the backpack sprayer. The STADD is 0.013 mg/kg/day for M/L/As handling EC products and 0.100 mg/kg/day for M/L/As handling WP endosulfan products. For M/L/As handling EC products, annual exposures were estimated to occur during the two months shown in Figure 9.

Table 23. Seasonal, Annual, and Lifetime Exposure Estimates for Endosulfan Handlers Using Handheld Equipment

Scenario [a]	SADD [b] (mg/kg/day)			AADD [c] (mg/kg/day)			LADD [d] (mg/kg/day)		
	Dermal	Inhalation	Total	Dermal	Inhalation	Total	Dermal	Inhalation	Total
BP [e]									
M/L/A	0.011	0.00002	0.011	0.002	0.000003	0.002	0.001	0.000001	0.001
HPHW [f]									
M/L/A	0.150	0.003	0.153	0.025	0.001	0.026	0.014	0.0003	0.014
LPHW [e]									
M/L/A EC	0.003	0.00002	0.003	0.0005	0.000003	0.0005	0.0003	0.000002	0.0003
M/L/A WP	0.015	0.0004	0.015	0.003	0.0001	0.003	0.001	0.00004	0.001

[a] No seasonal, annual, or lifetime exposure is anticipated for workers dipping nursery stock; that scenario is omitted from this table. Abbreviations: BP = backpack sprayer. EC = emulsifiable concentrate. LPHW = low pressure handwand. M/L/A = mixer/loader/applicator. WP = wettable powder.

[b] Seasonal Average Daily Dosage is a 90% upper confidence estimate calculated from the long-term exposure estimate given in Table 22. Application rate is maximum rate on product labels, which varied for each scenario; acres treated per day varies by scenario. Dermal absorption assumed to be 47.3% (Craine, 1988). Inhalation absorption assumed to be 100%. Body weight assumed to be 70 kg (Thongsinthusak *et al*., 1993). Calculation: SADD = [(long-term exposure) x (absorption) x (acres treated/day) x (application rate)]/(70 kg body weight).

[c] Annual Average Daily Dosage = SADD x (annual use months per year)/(12 months in a year).

[d] Lifetime Average Daily Dosage = AADD x (40 years of work in a lifetime)/(75 years in a lifetime).

[e] Estimates assumed handling of 40 gal/day (150 l/day; US EPA, 2001), containing 0.75 lb AI/100 gal (0.09 kg AI/100 l; maximum application for apricots, nectarines, peaches, and pecans), for a total of 0.3 lb AI/day (0.14 kg AI/day). Annual exposure estimate based on high-use period of 2 months, based on data from DPR (2006a).

[f] Estimates assumed handling of 1,000 gal/day (3,800 l/day; US EPA, 2001), containing 0.75 lb AI/100 gal (0.09 kg AI/100 l; maximum application for apricots, nectarines, peaches, and pecans), for a total of 7.5 lb AI/day (3.4 kg AI/day). Annual exposure estimate based on high-use period of 2 months.

Nursery Stock Dip

Nursery stock dipping may be done for treatment of cherry, peach and plum seedlings for peachtree borer. The dipping solution is prepared by mixing 1.25 lb AI in 40 gallons of water. Seedlings are immersed in the dipping solution so that roots and crowns are covered well above the grafting bud scar, then are either planted immediately or dried before storage.

In California, cherry, peach and plum trees are planted in January (UCCE, 2004). Examination of PUR data shows that endosulfan is infrequently applied to nursery stock, with applications reported on just one to six days each year between 2000 and 2004 (DPR, 2006a; data not shown). Therefore, seasonal, annual and lifetime exposures to endosulfan are not anticipated to occur during activities in these crops, and only short-term exposures were estimated.

No information is available on the amount of AI handled, although it is possible that thousands of seedlings are treated daily (Beauvais, 2004). For M/L exposure estimates, it was assumed that workers would handle 1.25 lb AI/day to prepare 40 gallons of dipping solution, and exposures were estimated based on surrogate data from PHED (1995). A closed-system was assumed, as required under California law (3 CCR 6746).

Because details about pesticide root dipping are lacking, exposure estimates for this scenario were based on the assumption that root dips with pesticides are similar to root dipping to protect roots from desiccation, except that pesticidal root dips require workers to wear clothing and PPE specified on pesticide product labels (Appendix 13). Applicators were assumed to immerse seedling roots into a container such as a bucket or vat while holding seedlings above roots, and that hands were immersed in the pesticide solution or slurry. Several models were evaluated to determine the best estimate of applicator exposure (Beauvais, 2004).

Applicator dermal exposure was estimated from equations in the Risk Assessment Guidance for Superfund, Part E (RAGS-E; U.S. EPA, 2004a). For dermal absorption of chemicals from water, RAGS-E incorporates the equations recommended by U.S. EPA (1992). These are based on a two-compartment model, in which the skin is assumed to be composed of two main layers, the stratum corneum and the viable epidermis, with the stratum corneum as the main barrier. The permeability coefficient of the stratum corneum to a chemical (K_p) is estimated based on physical properties of the chemical, including the molecular weight and log K_{ow}. The model assumes that absorption of material deposited on the skin continues long after the exposure has ended. The series of calculations is summarized in Appendix 13. The formula used to estimate dermal exposure requires AI concentration in mg/L units. Solution concentration was calculated with the following relationships: 2 lbs AI/40 gallons solution = 0.05 lbs AI/gallon = 22,727 mg/gallon and 1 gallon = 3.79 L. The concentration of a solution containing 2 lbs AI in 40 gallons is about 6,000 mg/L (this concentration is greater than the water solubility of endosulfan; however, products contain additives to increase AI solubility in water).

Most of the applicator exposure is anticipated to be to hands. However, available information suggests that applicators may also be exposed by splashes or drips on the forearms, torso, and legs (Beauvais, 2004). Although this exposure is not immersion in the same way as hands, in the absence of a better approach these exposed body surfaces were also considered in exposure estimates. Dermal exposure via hands and non-hand areas was assumed to be decreased by 90% in workers wearing the required gloves and coveralls over long-sleeved shirt and pants (Thongsinthusak *et al.*, 1991; Aprea *et al.*, 1994). The surface area of both hands was assumed to be 904 cm^2, the value of combined male and female medians (EPA, 1997). The surface area of the other parts of a worker's body anticipated to be exposed was assumed to be 7,306 cm^2, the total surface area of chest/stomach, forearms, front of thighs and lower legs based on combined male and female medians (EPA, 1997).

As with dermal exposure, no inhalation exposure monitoring data are available for workers dipping nursery stock. Inhalation exposure is anticipated to occur, assuming that dipping tanks have a free liquid surface from which chemicals can volatilize into the air.

Several models have been proposed to estimate inhalation exposure resulting from volatilization of chemicals from aqueous solutions; three models used by U.S. EPA to estimate exposure to chemicals evaporated from containers or pools of liquid were evaluated in Beauvais (2004). Applicator inhalation exposure was estimated from equations in SWIMODEL (U.S. EPA, 2003). SWIMODEL uses well-accepted screening exposure assessment equations to calculate swimmers' total exposure expressed, modified from equations used by Beech (1980). For inhalation exposure, SWIMODEL assumes 100% absorption of inhaled chemical. Exposure estimates are based on chemical intakes only; the model does not address metabolism or excretion (U.S. EPA, 2003). Exposure calculations from SWIMODEL are summarized in Appendix 14. Inhalation exposure estimates assumed a saturated vapor concentration (the vapor concentration calculated by SWIMODEL exceeded this value, and was considered unrealistically high).

STADD for M/Ls are 0.0001 mg/kg/day and 0.002 mg/kg/day for M/Ls handling EC and WP products, respectively. STADD are 41.4 mg/kg/day for applicators (Table 22).

Reentry Exposure

<u>Overview</u>

Representative exposure scenarios for reentry workers were selected as described above in the Exposure Scenarios section. As exposure data were not available for workers reentering crops treated with endosulfan, exposures were estimated from DFR values summarized in Table 10 and TCs from studies with surrogate chemicals (i.e., it was assumed that residue transfer is not chemical-specific).

The major route of pesticide exposure for reentry workers is the dermal route; contact with treated surfaces, especially foliage, causes pesticide residues to be transferred to the skin. The TC is a parameter estimating rate of contact between the worker and treated surface, based on empirical data from studies in which both DFR and dermal exposure have been measured. The TC for an activity is calculated by dividing DFR from a treated crop into the dermal exposure measured for workers performing reentry activities in the crop: TC (cm^2/hr) = [dermal exposure (µg/hr)]/[DFR (µg/cm^2)]. As the TC depends on the intensity of contact with the contaminated surface, it is activity- and surface-specific; however, TCs are only available for a limited number of activities and crops. When specific TCs were not available, TCs from similar crops and activities were used instead.

The absorbed daily dosage (ADD) was calculated as shown in the equation below (Zweig *et al*., 1984; Zweig *et al*., 1985), using the dermal absorption rate (DA) of 47.3%, based on Craine (1988); default exposure duration (ED) of 8 hours; and default body weight (BW) of 70 kg (Thongsinthusak *et al*., 1993). Short-term exposure estimates for fieldworkers are given in Table 24, reported as mg/kg/day (a conversion of 1 mg = 1,000 µg was done).

$$ADD\,(\mu g / kg / day) = \frac{DA \times DFR\,(\mu g / cm^2) \times TC\,(cm^2 / hr.) \times ED\,(hrs./ day)}{BW(kg)}$$

Reentry workers are not required to wear PPE unless entering fields before expiration of the restricted entry interval (REI). Because a lot of reentry work occurs in hot weather and for several hours each day, PPE is often not worn by fieldworkers unless required for early reentry. Therefore, fieldworker exposure estimates were based on an assumption that no PPE would be worn.

Table 24. Short-term Exposures to Endosulfan Estimated for Reentry Workers

Exposure scenario	DFR ($\mu g/cm^2$) [a]	TC (cm^2/hr) [b]	STADD (mg/kg/day) [c]
Almonds, Thinning	0.34	500	0.009
Broccoli, Hand Harvesting	0.22	5,000	0.030
Broccoli, Scouting	0.39	4,000	0.084
Citrus, Scouting	0.34	1,000	0.018
Sweet Corn, Hand Harvesting	0.58	17,000	0.533
Cotton, Scouting	0.58	2,000	0.063
Cucumbers, Hand Harvesting	0.39	2,500	0.053
Grapes, Cane Turning	0.62	10,000	0.335
Lettuce, Scouting	2.00	1,500	0.162
Ornamental Cut Flowers, Hand Harvesting	0.42	7,000	0.159
Ornamental Plants, Hand Harvesting	0.42	400	0.009
Peaches, Thinning	0.34	3,000	0.055
Potatoes, Scouting	0.39	1,500	0.032
Strawberries, Hand Harvesting	0.83	1,500	0.067
Tomatoes, Hand Harvesting	0.39	1,000	0.021

[a] Dislodgeable foliar residue (DFR) values from Table 10.
[b] Transfer coefficient (TC) is rate of skin contact with treated surfaces. TC references: Cotton scouting (Dong, 1990); peach (Dawson, 2003); ornamental plants (Klonne *et al.*, 2000); all other crops (U.S. EPA, 2000a).
[c] Short-term Absorbed Daily Dosage (STADD) calculated as described in text. Exposure estimates are for dermal route, as inhalation route assumed to be insignificant. Assumptions include:

- Exposure duration = 8 hr
- Dermal Absorption = 47.3% (Craine, 1988)
- Body weight = 70 kg (Thongsinthusak *et al.*, 1993)

Scouting may occur at any time, and was assumed to occur after all applications. Information about when other reentry activities might occur was obtained from crop profiles prepared by the University of California Cooperative Extension and the Vegetable Research and Information Center (UCCE, 2004; VRIC, 2004), and from the California Farm Worker Activity Profile (CFWAP; Edmiston *et al.*, 1999). CFWAP is a DPR database compiled from a number of sources, including the California Employment Development Department, U.S. Department of Agriculture, California Department of Food and Agriculture and the University of California Cooperative Extension. CFWAP includes information on harvested acreage, cultural practices necessary to grow a crop, and the dates of peak and overall activity periods for work activities such as harvesting and thinning, based on data from 1994. More recent data are not available at the present time.

Short-term exposures were estimated at the expiration of the 2-day REI for all activities except hand harvesting, which was estimated at the expiration of the pre-harvest intervals (PHI); if PHI was less than 2 days, then the REI was used. For seasonal and annual exposure estimates, it was assumed that workers would enter fields at some average time after the expiration of the REI or PHI, based on how frequently specific activities generally occur in general crop types (UCCE, 2004). For longer-term exposure estimates it was assumed that workers would not always enter fields at the expiration of the REI. Seasonal and annual exposures were estimated at an assumed average reentry of REI (or PHI, if longer than REI) plus 7 – 10 days. These assumed averages were not based on data; rather, they were based on the reasonable, conservative assumption that workers may enter fields an average of 7 – 10 days after expiration of the REI or PHI. Table 25 contains seasonal, annual, and lifetime exposures estimates for reentry activities.

Table 25. Seasonal, Annual, and Lifetime Exposures to Endosulfan Estimated for Reentry Workers [a]

Exposure scenario	DFR ($\mu g/cm^2$) [b]	SADD (mg/kg/day) [c]	AADD (mg/kg/day) [d]	LADD (mg/kg/day) [e]
Broccoli, Hand Harvesting [f]	0.029	0.008	0.001	0.0007
Broccoli, Scouting [g]	0.055	0.012	0.004	0.002
Sweet Corn, Hand Harvesting [h]	0.082	0.075	0.006	0.003
Cotton, Scouting [f]	0.082	0.009	0.001	0.0008
Cucumbers, Hand Harvesting [f]	0.055	0.007	0.001	0.0007
Grapes, Cane Turning [g]	0.26	0.141	0.047	0.025
Lettuce, Scouting [i]	0.055	0.004	0.002	0.001
Peaches, Thinning [f]	0.17	0.028	0.005	0.002
Potatoes, Scouting [j]	0.055	0.004	0.002	0.001
Tomatoes, Hand Harvesting [g]	0.17	0.009	0.003	0.002

[a] No seasonal, annual, or lifetime exposure estimates were prepared for workers reentering treated almond or citrus orchards or strawberry fields. Infrequent endosulfan use is reported on these crops

[b] Dislodgeable foliar residue (DFR) values from Table 10.

[c] Seasonal Average Daily Dosage is a mean estimate of absorbed dose, calculated as described in text. Exposure estimates are for dermal route, as inhalation route assumed to be insignificant. Transfer coefficients are given in Table 24.

[d] Annual Average Daily Dosage = SADD x (annual use months per year)/(12 months in a year).

[e] Lifetime Average Daily Dosage = AADD x (40 years of work in a lifetime)/(75 years in a lifetime).

[f] Annual exposure estimate based on high-use period of 2 months, based on data from DPR (2006a).

[g] Annual exposure estimate based on high-use period of 4 months.

[h] Annual exposure estimate based on high-use period of 1 month.

[i] Annual exposure estimate based on high-use period of 5 months.

[j] Annual exposure estimate based on high-use period of 6 months.

Most reentry activities are not expected to result in pesticide exposure throughout the year. This is true because pesticides like endosulfan are not necessarily applied all year in all crops, and because many activities are performed only seasonally. To estimate when endosulfan applications might occur throughout the year, five-year averages were plotted of monthly PUR data (numbers of acres treated) for endosulfan applications to the crops of interest in one or more high-use counties. These average use patterns were compared to information about when reentry activities might occur. Annual exposure to endosulfan is assumed to be limited to the months when activities overlap relatively high use (defined as 5% or more of annual use each month).

<u>Thinning Almonds</u>

The REI following endosulfan applications to almonds is 2 days. For exposure estimates, the estimated DFR 2 days post-application was used, as well as a TC of 500 cm^2/hr (U.S. EPA, 2000a). The STADD is 0.009 mg/kg/day.

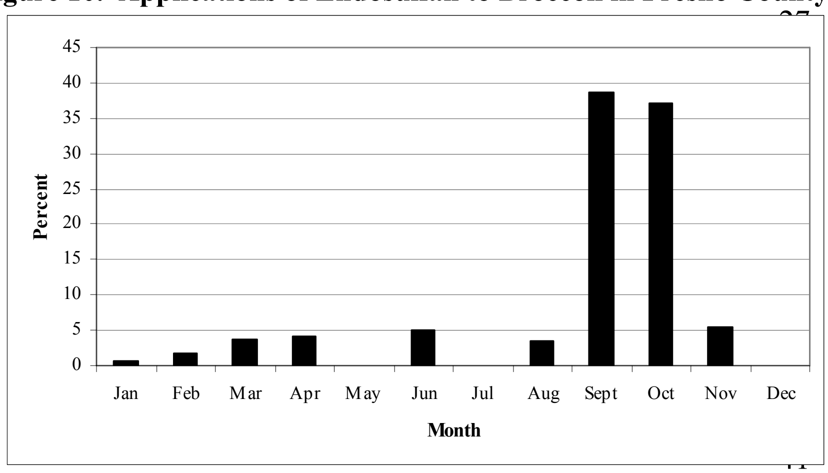
Examination of PUR data shows that endosulfan is infrequently applied to almonds and other tree nuts (DPR, 2006a; data not shown). Therefore, seasonal, annual and lifetime exposures to endosulfan are not anticipated to occur during activities in these crops.

<u>Hand Harvesting Broccoli</u>

The PHI following endosulfan applications to broccoli is 7 days. For exposure estimates, the estimated DFR 7 days post-application was used, as well as a TC of 5,000 cm^2/hr (U.S. EPA, 2000a). The STADD is 0.030 mg/kg/day.

Based on information in CFWAP (Edmiston *et al.*, 1999), broccoli in the San Joaquin Valley is harvested October – March (late fall through early spring). Figure 10 summarizes all applications of endosulfan to broccoli in Fresno County, based on numbers of acres treated each month for the five-year interval 2000 – 2004.

Figure 10. Applications of Endosulfan to Broccoli in Fresno County, 2000 – 2004 [a]



[a] Percent calculations based on acres treated (DPR, 2006a; queried January 27, 2006).

The majority of use shown in Figure 10 occurred in June and September through November (i.e., more than 5% of annual use occurred during each of these months), which overlaps the typical harvest period by two months (in October and November). Annual exposure was estimated to occur during these two months.

Scouting Broccoli

The REI following endosulfan applications to broccoli is 2 days. For exposure estimates, the estimated DFR 2 days post-application was used, as well as a TC of 4,000 cm^2/hr (U.S. EPA, 2000a). The STADD is 0.084 mg/kg/day.

Scouting may occur at any time, and was assumed to potentially occur following pesticide use (e.g., to confirm efficacy of the application). The majority of endosulfan use on broccoli occurs in June and September through November (Figure 10). Annual exposure was estimated to occur during these four months.

Scouting Citrus

The REI following endosulfan applications to citrus is 2 days. For exposure estimates, the estimated DFR 2 days post-application was used, as well as a TC of 1,000 cm^2/hr, which also applies to other activities associated with non-bearing citrus, including weeding and irrigation (U.S. EPA, 2000a). As non-bearing citrus trees by definition have no fruit, neither thinning nor harvesting activities are anticipated to occur in citrus treated with endosulfan. The STADD for citrus scouts is 0.018 mg/kg/day.

Examination of PUR data shows that endosulfan is infrequently applied to citrus (DPR, 2006a; data not shown). Therefore, seasonal, annual and lifetime exposures to endosulfan are not anticipated to occur during activities in these crops.

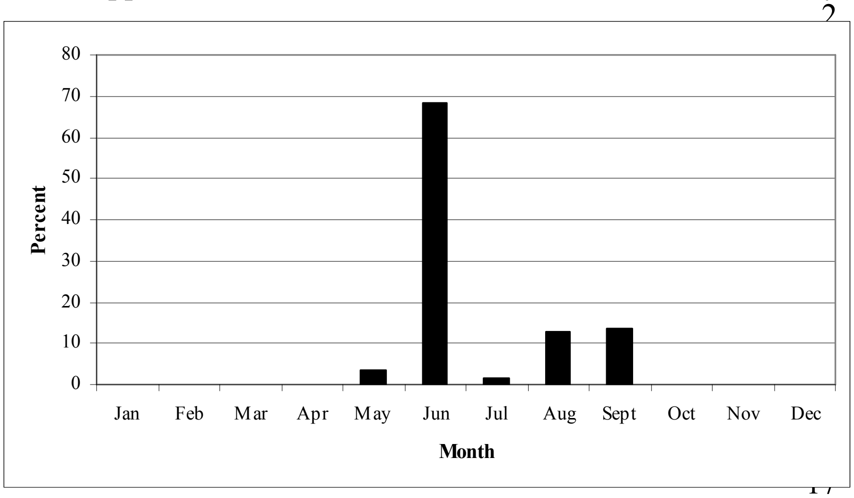
Hand Harvesting Sweet Corn

The PHI following endosulfan applications to sweet corn is one day. However, the REI is 2 days. For exposure estimates, the estimated DFR 2 days post-application was used, as well as a TC of 17,000 cm^2/hr (U.S. EPA, 2000a). The STADD is 0.533 mg/kg/day.

Based on a crop profile for sweet corn in California (UCCE, 2004), spring corn is generally harvested from April through June; fall corn is generally harvested in November and December. Figure 11 summarizes all applications of endosulfan to sweet corn in Fresno County, based on numbers of acres treated each month for the five-year interval 2000 – 2004.

Figure 11 shows that endosulfan was not applied during the fall corn harvest period. However, applications occurred during the spring harvest period (in May and June). Few acres were treated in May (15 acres, or 6 ha, was the mean area treated in May), suggesting that harvester exposure to endosulfan is unlikely in May. The most acres each year were treated in June (average: 276 acres or 112 ha). For annual exposure estimates, it was assumed that workers were exposed on each workday in June.

Figure 11. Applications of Endosulfan to Sweet Corn in Fresno County, 2000 – 2004 [a]



[a] Percent calculations based on acres treated (DPR, 2006a; queried January 26, 2006).

Scouting Cotton

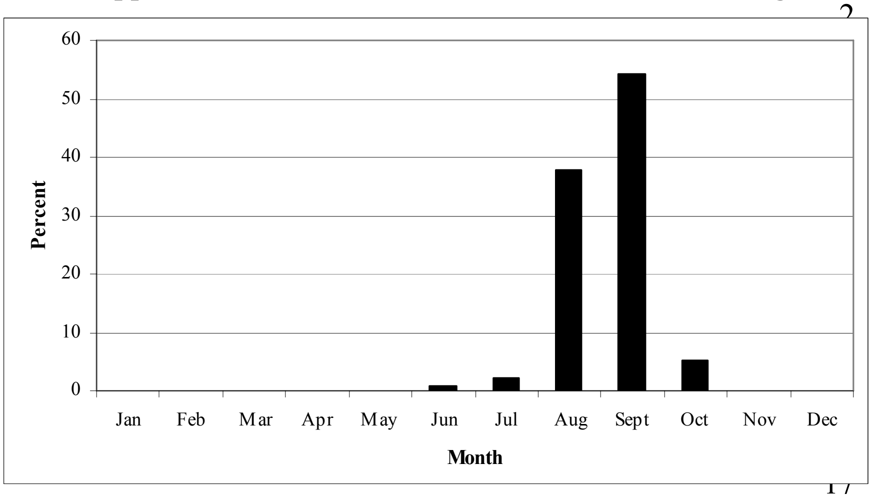
The REI following endosulfan applications to cotton is 2 days. For exposure estimates, the estimated DFR 2 days post-application was used. Transfer factors were derived from a series of studies in which several organophosphates were applied to cotton (Ware *et al.*, 1973, 1974, 1975). Geometric mean transfer factors were computed for bare hands (950 cm^2/hr), the clothed upper body (102 cm^2/hr), and the clothed lower body (964 cm^2/hr). The potential dermal transfer factor for the whole body of cotton scouts (2,000 cm^2/hr) was calculated by summing these individual geometric mean transfer factors (Dong, 1990). STADD for scouting in cotton is 0.063 mg/kg/day.

Scouting may occur at any time, and was assumed to potentially occur following pesticide use. Figure 12 summarizes all applications of endosulfan to cotton in Kern and Kings counties, based on numbers of acres treated each month for the five-year interval 2000 – 2004. The majority of endosulfan use on cotton occurs August and September (Figure 12). Annual exposure was estimated to occur during these two months.

Hand Harvesting Cucumbers

The PHI following endosulfan applications to cucumbers is 2 days. For exposure estimates, the estimated DFR 2 days post-application was used, as well as a TC of 2,500 cm^2/hr (U.S. EPA, 2000a). The STADD is 0.053 mg/kg/day.

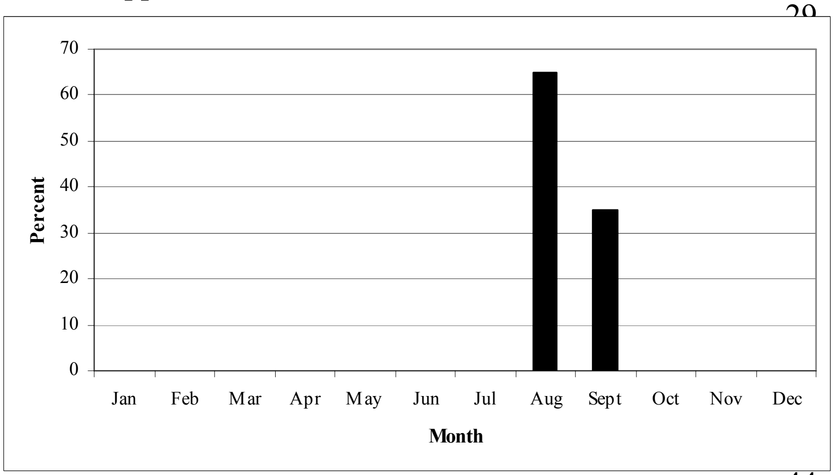
Figure 12. Applications of Endosulfan to Cotton in Kern and Kings Counties, 2000 – 2004 [a]



[a] Percent calculations based on acres treated (DPR, 2006a; queried January 26, 2006).

Based on a crop profile for hand-harvested cucumbers in California (UCCE, 2004), in the Central Valley harvesting generally occurs in August through October. Figure 13 summarizes all applications of endosulfan to cucumbers in Colusa County, based on numbers of acres treated each month for the five-year interval 2000 – 2004. Figure 13 shows that nearly all endosulfan applications occurred in August and September, during the early part of the typical harvest period. Annual exposure was estimated to occur during these two months.

Figure 13. Applications of Endosulfan to Cucumbers in Colusa County, 2000 – 2004 [a]



[a] Percent calculations based on acres treated (DPR, 2006a; queried January 26, 2006).

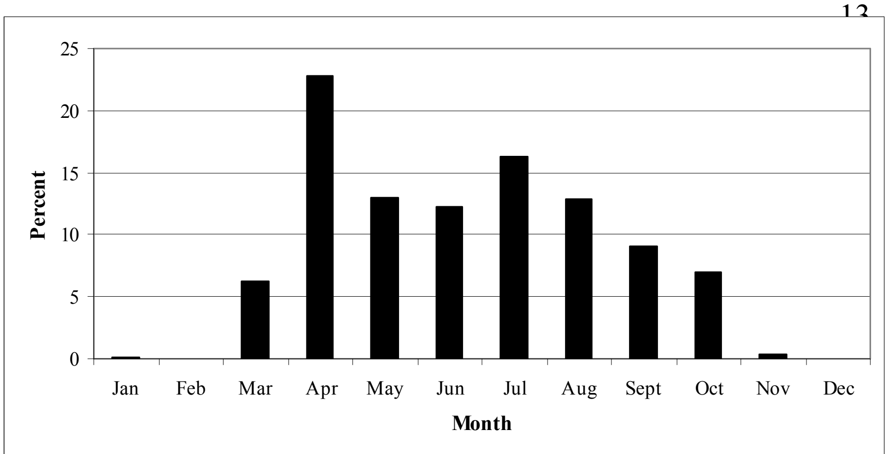
<u>Cane Turning/Leaf Pulling in Grapes</u>

The REI following endosulfan applications to grapes is 2 days. For exposure estimates, the estimated DFR 2 days post-application was used, as well as a TC of 10,000 cm^2/hr (U.S. EPA, 2000a). The STADD is 0.335 mg/kg/day.

Based on information in CFWAP (Edmiston *et al.*, 1999), leaf pulling in table grapes and wine grapes in the San Joaquin Valley occurs from April – July. Figure 13 summarizes all applications of endosulfan to grapes in Kern, Kings and Tulare counties, based on numbers of acres treated each month for the five-year interval 2000 – 2004.

Figure 14 shows that most use occurred from March through October (i.e., more than 99% of annual use occurred in this interval), which completely overlaps the typical activity period for leaf pulling and cane turning. Annual exposure was estimated to occur during the four months that leaf pulling is typically done (April – July).

Figure 14. Use of Endosulfan on Grapes in Kern, Kings and Tulare Counties, 2000 – 2004 [a]



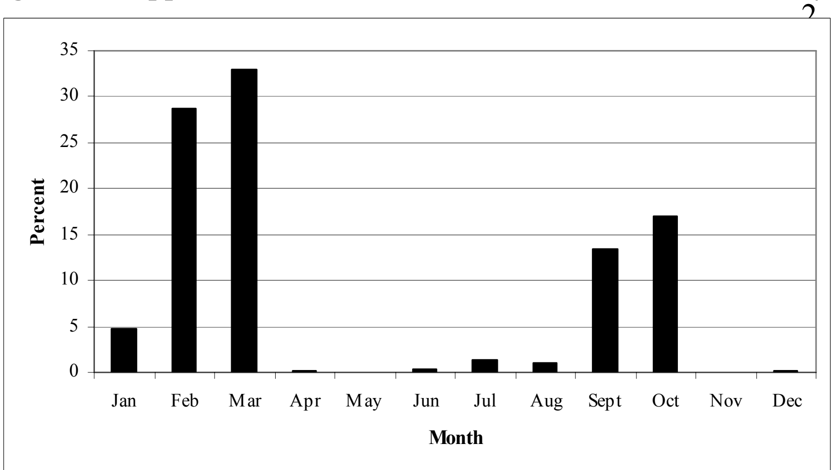
[a] Percent calculations based on acres treated (DPR, 2006a; queried January 26, 2006).

<u>Scouting Lettuce</u>

The REI following endosulfan applications to lettuce is 2 days. To calculate exposure estimates, a DFR of 2.0 μg/cm^2 was used, as well as a TC of 1,500 cm^2/hr (U.S. EPA, 2000a). The STADD is 0.162 mg/kg/day.

Scouting may occur at any time, and was assumed to potentially occur following pesticide use. Figure 15 summarizes all applications of endosulfan to lettuce in Fresno County, based on numbers of acres treated each month for the five-year interval 2000 – 2004. The majority of annual endosulfan use on lettuce occurs in two peaks, one from January through March and one from September through October; these five months account for about 97% of annual applications (Figure 15). Annual exposure was estimated to occur during these five months.

Figure 15. Applications of Endosulfan to Lettuce in Fresno County, 2000 – 2004 [a]



[a] Percent calculations based on acres treated (DPR, 2006a; queried January 26, 2006).

<u>Hand Harvesting Ornamentals - Flowers</u>

There is no PHI specified following endosulfan applications to ornamental plants, as these are not used for food (PHI are based on residue levels in food crops). The REI following endosulfan applications is 2 days. For exposure estimates, the estimated DFR 2 days post-application was used, as well as a TC of 7,000 cm^2/hr (U.S. EPA, 2000a). The STADD is 0.159 mg/kg/day.

Examination of PUR data suggests that endosulfan is infrequently applied to nursery and greenhouse-grown flowers (DPR, 2006a; data not shown). Therefore, seasonal, annual and lifetime exposures to endosulfan are not anticipated to occur during activities in these crops.

<u>Hand Harvesting Ornamental Plants – Trees and Shrubs</u>

There is no PHI specified following endosulfan applications to ornamental plants, as these are not used for food (PHI are based on residue levels in food crops). The REI following endosulfan applications is 2 days. For exposure estimates, the estimated DFR 2 days post-application was used, as well as a TC of 400 cm^2/hr (Klonne *et al*., 2000). The STADD is 0.009 mg/kg/day.

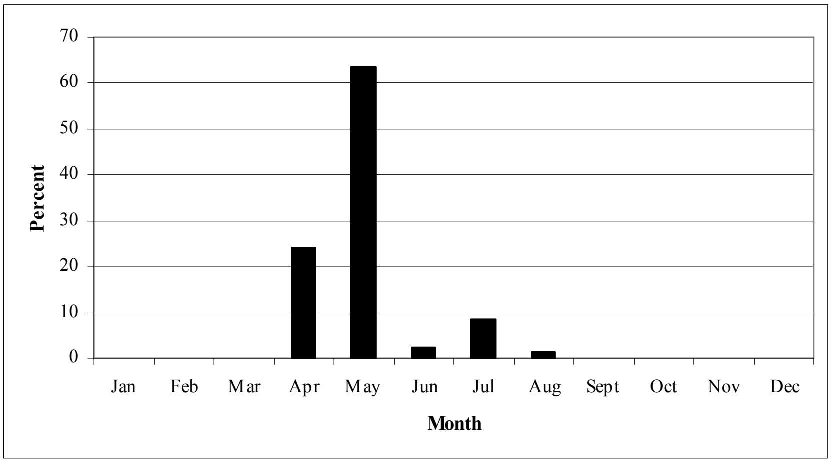
Examination of PUR data suggests that endosulfan is infrequently applied to container-grown ornamentals (DPR, 2006a; data not shown). Therefore, seasonal, annual and lifetime exposures to endosulfan are not anticipated to occur during activities in these crops.

<u>Thinning Peaches</u>

The REI following endosulfan applications to peaches is 2 days. For exposure estimates, the estimated DFR 2 days post-application was used, as well as a TC of 3,000 cm^2/hr (Dawson, 2003). STADD is 0.055 mg/kg/day.

Figure 16 summarizes all applications of endosulfan to peaches in Fresno County, based on numbers of acres treated each month for the five-year interval 2000 – 2004 (DPR, 2006a; queried January 26, 2006). The majority of annual endosulfan use on peaches occurs in two peaks, one from April through May and another in July; these three months account for 95% of annual applications (Figure 16). Annual exposure was estimated to occur during these three months.

Figure 16. Applications of Endosulfan to Peaches in Los Angeles County, 2000 – 2004 [a]



[a] Percent calculations based on acres treated (DPR, 2006a; queried January 26, 2006).

Scouting Potatoes

The REI following endosulfan applications to potatoes is 2 days. For exposure estimates, the estimated DFR 2 days post-application was used, as well as a TC of 1,500 cm^2/hr (U.S. EPA, 2000a). The STADD is 0.032 mg/kg/day.

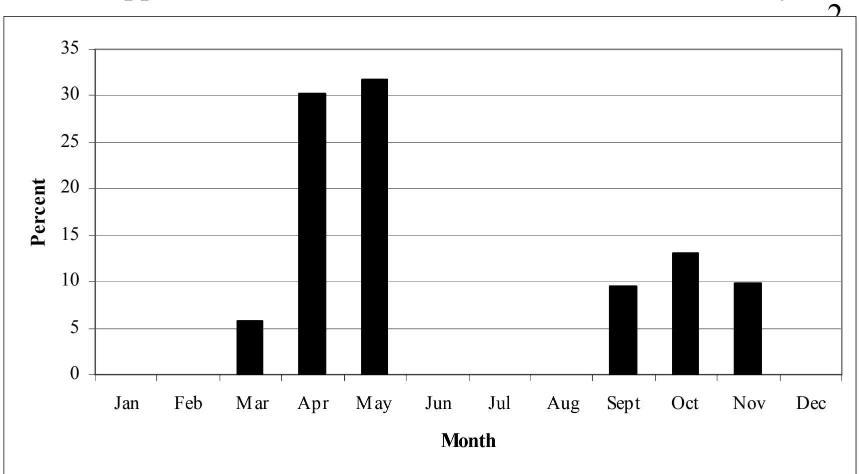
Scouting may occur at any time, and was assumed to potentially occur following pesticide use. Figure 17 summarizes all applications of endosulfan to potatoes in Kern County, based on numbers of acres treated each month for the five-year interval 2000 – 2004. Endosulfan use on potatoes occurs in two peaks, one from March through May and another from September through November (Figure 17). Annual exposure was estimated to occur during these six months.

Hand Harvesting Strawberries

The PHI following endosulfan applications to strawberries is 2 days. For exposure estimates, the estimated DFR 2 days post-application was used, as well as a TC of 1,500 cm^2/hr (U.S. EPA, 2000a). The STADD is 0.067 mg/kg/day.

Examination of PUR data shows that endosulfan is infrequently applied to strawberries (DPR, 2006a; data not shown). Therefore, seasonal, annual and lifetime exposures to endosulfan are not anticipated to occur during reentry in strawberries.

Figure 17. Applications of Endosulfan to Potatoes in Kern County, 2000 – 2004 [a]



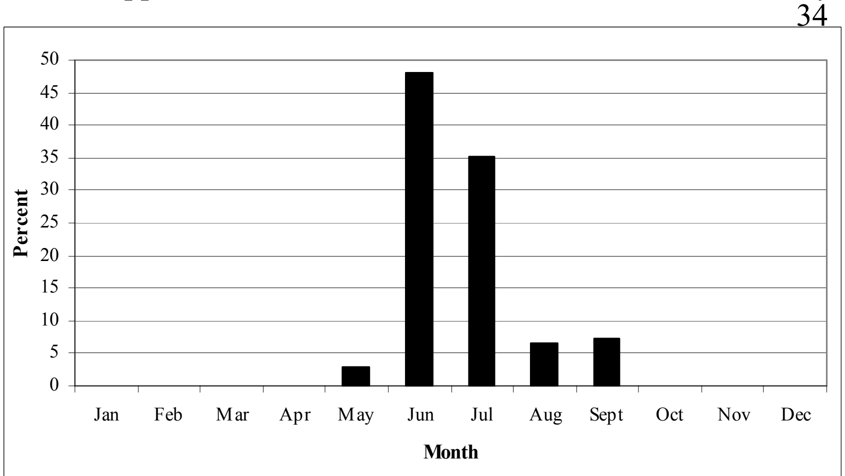
[a] Percent calculations based on acres treated (DPR, 2006a; queried January 26, 2006).

Hand Harvesting Tomatoes

The PHI following endosulfan applications to tomatoes is 2 days. For exposure estimates, the estimated DFR 2 days post-application was used, as well as a TC of 1,000 cm^2/hr (U.S. EPA, 2000a). The STADD is 0.021 mg/kg/day.

Based on information in CFWAP (Edmiston *et al.*, 1999), tomatoes are harvested in Fresno County from May through November. Figure 18 summarizes all applications of endosulfan to tomatoes in Fresno County, based on numbers of acres treated each month for the five-year interval 2000 – 2004. Figure 18 shows that most use occurred from June through September (i.e., about 97% of annual use occurred in this interval). This completely overlaps the typical activity period for harvesting. Annual exposure was estimated to occur during these four months.

Figure 18. Applications of Endosulfan to Tomatoes in Fresno County, 2000 – 2004 [a]



[a] Percent calculations based on acres treated (DPR, 2006a; queried January 27, 2006).

Mitigation Measures Proposed by U.S.EPA

Several measures were proposed by U.S. EPA (2002a) to mitigate dietary, occupational, and environmental risks of endosulfan use. Proposed measures that would affect handler and reentry exposure estimates are summarized in Appendix 15. Revised exposure estimates, reflecting anticipated exposures if these measures were implemented, are summarized in Appendix 15.

Proposed mitigation measures include deleting endosulfan use on several crops; deleting uses of endosulfan WP products on several other crops; forbidding aerial applications of WP products on several crops; requiring closed M/L systems for aerial applications of EC endosulfan products on several crops; and requiring closed cabs for airblast applications to tree crops. In addition, all WP products must be in water-soluble packaging, which would likely preclude the use of WP products by M/L/As using LPHWs. Maximum application rates, seasonal application rates, and numbers of applications allowed each season were reduced on many crops. Finally, REIs were increased for nearly all crops. Refer to Appendix 15 for a list of crops and changes.

Many of the mitigation measures proposed in U.S. EPA (2002a) are still pending. In September 2004, U.S. EPA released a progress report on regulatory decisions relating to the reregistration of several AIs, including endosulfan (U.S. EPA, 2004b). According to this report, U.S. EPA has requested several studies from registrants in data call-ins issued in August 2004. Results from these studies, as well as product labels revised in response to mitigation measures proposed in the RED, are anticipated to be submitted to U.S. EPA in 2005 (U.S. EPA, 2004b).

Ambient Air and Bystander Exposures

Ambient air and application site air monitoring detected endosulfan, suggesting that the public may be exposed to airborne endosulfan. Individuals might be exposed to endosulfan if they are working adjacent to fields that are being treated or have recently been treated (bystander exposure). In addition, air monitoring conducted in Fresno County suggests that airborne endosulfan exposures are possible even in areas that are far from application sites (ambient air exposure). Estimates of public exposure to airborne endosulfan are reported in this section.

<u>Ambient air</u>

As explained in the previous paragraph, ambient air exposures to endosulfan can occur far from application sites. Therefore, exposures to endosulfan in ambient air are anticipated to be equal to or less than bystander exposures to endosulfan, as the highest pesticide concentrations in air occur adjacent to an application (MacCollom *et al*., 1968; Siebers *et al*., 2003). Bystander exposure estimates are thus health-protective estimates for ambient air exposures, and are considered to also represent ambient air exposures to endosulfan.

Bystanders at application sites

To estimate bystander exposure to endosulfan in air, data were used from application site monitoring in a 1997 study in San Joaquin County (ARB, 1998). Stations (one each east, west and south, and two north) were located 6.4 – 16.5 m from the edge of the orchard. Table 15 summarizes endosulfan concentrations during several monitoring periods at each of these stations. Bystander exposure estimates are given in Table 26. The 24-hour time-weighted average (TWA) for the east monitoring station (24-hour TWA = 1.63 μg/m^3) was used to estimate short-term exposure (this is referred to in Table 26 as the short-term concentration). The application rate used in the study (1.5 lbs AI/acre, or 1.7 kg AI/ha) was below the maximum rate allowed on apples (2.5 lbs AI/acre, or 2.8 kg AI/ha), suggesting that bystanders near fields where the maximum allowed rate is used would be exposed to higher concentrations than were measured by ARB (1998). Concentrations are assumed to be directly proportional to application rate, and to adjust for concentrations associated with the maximum endosulfan application rate in estimating short-term exposures the 24-hour TWA was multiplied by 1.67 (2.5 divided by 1.5). STADD for bystanders is 0.00160 mg/kg/day for infants and 0.00076 mg/kg/day for adults.

Table 26. Bystander Exposure Estimates for Persons Exposed to Endosulfan [a]

<table>
<tr><th rowspan="2">Site</th><th colspan="2">Air concentration [b] (μg/m³)</th><th rowspan="2">STADD [c] (mg/kg/day)</th><th rowspan="2">Seasonal ADD [d] (mg/kg/day)</th><th rowspan="2">Annual ADD [e] (mg/kg/day)</th></tr>
<tr><th>Short-term</th><th>Long-term</th></tr>
<tr><td>Infants</td><td rowspan="2">2.72</td><td rowspan="2">0.952</td><td>0.00160</td><td>0.00056</td><td>0.000047</td></tr>
<tr><td>Adults</td><td>0.00076</td><td>0.00027</td><td>0.000022</td></tr>
</table>

[a] Estimates based on total endosulfan concentrations from monitoring conducted in San Joaquin County (application site for bystander exposure) in 1997 (ARB, 1998).

[b] Arithmetic mean and standard deviation (SD). Calculated using ½ limit of quantification (LOQ) for samples <LOQ. See Table 15 for the full application site monitoring data set. Concentrations are from the East station, which was the application air monitoring site with the highest endosulfan TWA concentrations (Table 15). Short-term exposure estimates were multiplied by 1.67, because the application rate used in the study (1.5 lbs AI/acre, or 1.7 kg AI/ha) was below the maximum rate allowed on apples (2.5 lbs AI/acre, or 2.8 kg AI/ha). Seasonal and annual exposure estimates were not adjusted for differences in application rate.

[c] Short-Term Absorbed Daily Dosage (mg/kg/day) = (short-term concentration) x (inhalation rate). Calculation assumptions include:

- Infant inhalation rate = 0.59 m^3/kg/day (Layton, 1993; U.S. EPA, 1997)
- Adult inhalation rate = 0.28 m^3/kg/day (Wiley *et al*., 1991; U.S. EPA, 1997; OEHHA, 2000)
- Inhalation absorption is assumed to be 100%

[d] Seasonal ADD = (long-term concentration) x (inhalation rate). Calculation assumptions as above.

[e] Annual ADD = (Seasonal ADD) x (annual use months per year)/12. Annual exposure estimates are based on high-use period of 1 month, as repeated applications adjacent to any one individual are considered unlikely for longer intervals.

Bystanders are generally anticipated to experience only acute exposures, with concentrations greater than ambient for less than one week at a time. Nevertheless, effects of each exposure might persist longer than a week, suggesting that repeated exposures occurring within a few weeks of one another might constitute seasonal and annual exposures. Endosulfan use is allowed between one and three times per year on most crops, suggesting that even if more than one field is treated in an area that seasonal and annual bystander exposures are unlikely. However, potatoes and tomatoes may receive up to six endosulfan applications per year, with no minimum interval specified between applications. Individuals in areas where tomatoes and potatoes are grown might experience season and annual exposures. Unlike short-term exposures, seasonal and annual exposure estimates do not include an adjustment to the maximum allowed application rate, as repeated applications at the maximum rate are considered unlikely. Estimates were based on an assumed high-use period of 1 month, as repeated applications adjacent to any one individual are considered unlikely for longer intervals. Seasonal ADD estimates for bystander exposures to endosulfan are 0.00056 mg/kg/day for infants and 0.00027 mg/kg/day for adults. Annual ADD estimates for bystanders are 0.000047 mg/kg/day for infants and 0.000022 mg/kg/day for adults.

Swimmer Exposures

As summarized previously in the Environmental Concentrations section, endosulfan residues have been detected in surface waters in California. Exposures of adults and children swimming in surface waters were estimated based on equations listed in U.S. EPA (2003). These calculations are summarized below.

The endosulfan dose absorbed dermally was estimated with the following equation:

$$ADR = C_w * SA * ET * K_p * CF1$$

where ADR = absorbed dose rate (mg/day); C_w = concentration of AI in water (mg/L); SA = surface area exposed (cm^2); ET = exposure time (hours/day); K_p = permeability coefficient; and CF1 = volume unit conversion factor (L/1,000 cm^3). The 95th percentile total endosulfan concentration of 0.15 µg/L (C_w = 0.00015 mg/L), calculated from the 95th percentile concentrations reported in Table 16, was used in estimating short-term swimmer exposure (STADD). For long-term exposures, the median total endosulfan concentration of 0.010 µg/L (C_w = 0.000010 mg/L) was calculated from the 50th percentile concentrations in Table 16. Default values were used for SA and ET. For adults, SA = 18,150 cm^2 and for a 6 year-old child, SA = 8,545 cm^2 (U.S. EPA, 1997). For short-term exposures, the ET was assumed to be 5 hours (U.S. EPA, 2003). For long-term exposures, the ET was assumed to average 2.3 hours/day for children and 1.3 hours/day for adults (U.S. EPA, 2003). Weather was assumed to be suitable for outdoor swimming for 100 days each year. The permeability coefficient for endosulfan calculated in Appendix 13, 0.0112 cm/hr, was used for K_p.

The endosulfan dose absorbed from incidental non-dietary ingestion was estimated with the following equation:

$$PDR = C_w * IR * ET$$

where PDR = potential dose rate via oral exposure per event (mg/event); C_w = concentration of AI in water (mg/L); IR = ingestion rate of pool water (L/hour); and ET = exposure time (hours/event). In calculating PDR, the same values were used for C_w and

ET as those used in calculating ADR. The ingestion rate (IR) was assumed to be 0.05 L/hr for children and 0.025L/hr for adults (U.S. EPA, 2003).

Both STADD and SADD were calculated from ADR and PDR by dividing by default body weights of 70 kg for an adult (Thongsinthusak *et al.*, 1993) and 24 kg for a 6 year-old child (U.S. EPA, 1997). Exposure estimates are summarized in Table 27. Inhalation exposure was assumed to be negligible, and was not included in swimmer exposure estimates. The total exposure was calculated by summing dermal and non-dietary ingestion exposure estimates. Total STADD is 0.00027 mg/kg/day for adults and 0.00156 mg/kg/day for children.

Table 27. Exposures to Endosulfan Estimated for Swimmers in Surface Waters [a]

Exposure scenario	STADD (mg/kg/day) [b]	SADD (mg/kg/day) [c]	AADD (mg/kg/day) [d]	LADD (mg/kg/day) [e]
Adult Dermal [f]	0.00000218	0.0000000378	0.0000000103	0.00000000517
Adult Non-Dietary Ingestion [g]	0.000268	0.00000464	0.00000127	0.000000636
Adult Total [h]	0.00027	0.00000468	0.00000128	0.000000641
Child Dermal [f]	0.00000299	0.0000000917	0.0000000251	0.0000000126
Child Non-Dietary Ingestion [g]	0.00156	0.0000479	0.0000131	0.00000656
Child Total [h]	0.00156	0.0000480	0.0000131	0.00000657

[a] Exposure estimates include dermal and ingestion routes, as inhalation route assumed to be insignificant. Endosulfan concentrations used in exposure estimates are from the Department of Pesticide Regulation Surface Water Database (DPR, 2004). The 95th percentile total endosulfan concentration of 0.15 μg/L, calculated from the 95th percentile concentrations reported in Table 16, was used in estimating short-term exposure. For long-term exposures, the median total endosulfan concentration of 0.010 μg/L was calculated from the 50th percentile concentrations reported in Table 16.

[b] Short-term Absorbed Daily Dosage (STADD) calculated as described in text. Swimmers were assumed to swim for 5 hours in a day (U.S. EPA, 2003). Body weight assumed to be 70 kg for adult (Thongsinthusak *et al.*, 1993) and 24 kg for child (U.S. EPA, 1997).

[c] Seasonal Average Daily Dosage is a mean estimate of absorbed dose, calculated as described in text. Swimmers were assumed to swim for an average of 2.3 hours/day for children and 1.3 hours/day for adults (U.S. EPA, 2003).

[d] Annual Average Daily Dosage = SADD x (100 days)/(365 days in a year).

[e] Lifetime Average Daily Dosage = AADD x (35 years of swimming)/(75 years in a lifetime).

[f] Dermal exposure estimates assume a median surface area of 18,150 cm^2 for adult and 8,565 cm^2 for a child (U.S. EPA, 1997).

[g] Incidental non-dietary ingestion assume an ingestion rate of 0.05 L/hour for children and 0.025 L/hr for adults (U.S. EPA, 2003).

EXPOSURE APPRAISAL

Handler Exposure Estimates

PHED

Exposure estimates for handlers were based on surrogate data, due to lack of acceptable, chemical-specific data. Exposure monitoring data from PHED were used to estimate handler exposures for the various application methods. PHED incorporates exposure data from many studies, each with a different minimum detection level for the analytical method used to detect residues in the sampling media. Moreover, as the detection of dermal exposure to the body regions was not standardized, some studies observed exposure to only selected body parts. Consequently, the subsets derived from the database for dermal exposure may have different numbers of observations for each body part, a fact which complicates interpretation of values taken from PHED. However, use of PHED data provided the best exposure estimates possible. U.S. EPA also relied on PHED data for handler exposure estimates (U.S. EPA, 2002b).

Upper confidence limits are used for seasonal and chronic estimates based on PHED. For these exposures, UCLs are used not because DPR believes that exposures are consistently greater than the population mean, but because available data are so sparse that it is likely that the sample mean is not close to the true population mean. In exposure monitoring, ranges of sample results can be quite broad, and can include values that are substantially higher than sample means (Grover *et al.*, 1986; Vercruysse *et al.*, 1999). Some studies have reported sample ranges that span as much as three orders of magnitude (e.g., Hines *et al.*, 2001). Thus, it is apparent that handlers could have exposures well above sample means; such estimates are not unreasonable. PHED data in particular pose difficulties because they are poorly characterized for the user, confounding assessment of the match between any given subset and the exposure scenario it is intended to represent. UCLs are used by DPR to address concerns specific to PHED (Powell, 2002).

Data quality grades in PHED have been assigned based on Quality Assurance/Quality Control data provided in exposure study reports. Grades A and B are high-quality grades, with lab recoveries of 90-110% and 80-100%, respectively (field recoveries range 70-120% and 50-120%); grade C represents moderate quality, with lab and field recoveries of 70-120% and 30-120%, respectively; grade D represents poor quality, with lab recovery of 60-120% and field recovery that is either in the range of 30-120% or missing (i.e., no field recovery data are necessary for studies assigned Grade D); E is the lowest quality grade, and is assigned to PHED data that do not meet basic quality assurance (U.S. EPA, 1998a). Data quality grades for each PHED data set used in exposure estimates are summarized in the first table of each appendix. Data quality was generally high to moderate in the data sets used to generate exposure estimates.

The appendices also summarize numbers of observations contained in each PHED subset. Subsets for M/L/A using low-pressure hand wand or backpack sprayer had 9-11 observations for each body part. This is a very small number of observations, increasing the uncertainty that estimates generated from these subsets have captured the full range of variability occurring even in typical uses. In some cases, all data within a subset might have been collected in a single study. Other subsets that are rather small include M/L/A using high-pressure hand wand (7-13 observations); M/L handling WP in WSP (6-15 observations); and aerial applicator (9-17 observations).

DPR and U.S. EPA Estimates

U.S. EPA also uses PHED to estimate handler exposure; however, U.S. EPA approaches PHED data somewhat differently than DPR. First, as explained in U.S. EPA's policy for use of PHED data (U.S. EPA, 1999): "Once the data for a given exposure scenario have been selected, the data are normalized (i.e., divided by) by the amount of pesticide handled resulting in standard unit exposures (milligrams of exposure per pound of active ingredient handled). Following normalization, the data are statistically summarized. The distribution of exposure values for each body part (i.e., chest upper arm) is categorized as normal, lognormal, or "other" (i.e., neither normal nor lognormal). A central tendency value is then selected from the distribution of the exposure values for each body part. These values are the arithmetic mean for normal distributions, the geometric mean for lognormal distributions, and the median for all "other" distributions. Once selected, the central tendency values for each body part are composited into a "best fit" exposure value representing the entire body." In other words, U.S. EPA uses various central tendency estimates (often the geometric mean or median, as PHED data rarely follow a normal distribution), while DPR believes the arithmetic mean is the appropriate statistic regardless of the sample distribution (Powell, 2003). Second, DPR uses a 95th percentile upper bound estimate for short-term exposure estimates, while U.S. EPA uses a central tendency estimate for all exposure durations. Third, as explained in the Exposure Assessment section, DPR calculates 90% UCLs for both upper bound and mean exposures, while U.S. EPA does not. The differences between short-term exposure estimates calculated according to DPR and U.S. EPA policies are summarized in Table 28 for an example scenario, aerial applicator.

In Table 28, the exposure rate estimated by U.S. EPA is 5.068 µg AI/lb handled (U.S. EPA, 2002b); the exposure rate calculated according to DPR policy is 133.286 µg AI/lb handled. These values differ substantially, not only for the reasons explained above, but also because U.S. EPA assumes use of closed cockpits in all aerial exposure estimates; if planes with open cockpits can be used, U.S. EPA policy is to require an additional 10-fold safety factor in the risk calculation (U.S. EPA, 1998b). If DPR were to assume a closed cockpit, the total exposure rate would be 46.7 µg AI/lb handled; this estimate was included in Table 28 to show the extent to which assumption of an open cockpit affects DPR exposure estimates. The most recent information available about equipment used by aerial applicators shows that open cockpits are relatively rare, but may still be used (NAAA, 2004).

The STADD estimated by DPR is 0.790 mg/kg/day, and the corresponding exposure estimate calculated by U.S. EPA is 0.1312 mg/kg/day. If closed cockpits were required, the DPR exposure estimate would only be 0.280 mg/kg/day, slightly more than twice the

U.S. EPA estimate. No chemical-specific exposure monitoring data were available for comparison with these estimates.

Although there are differences in how DPR and U.S. EPA calculate exposure estimates from PHED, there are also similarities. For example, groundboom applicator data in PHED are from studies in which subjects did not wear gloves. When using these data, both DPR and U.S. EPA (2002b) assign a 90% protection factor for exposure reduction for workers wearing gloves as required on product labels.

Table 28. Comparison of Aerial Applicator Exposure to Endosulfan Estimated From the Pesticide Handler Exposure Database by DPR and U.S. EPA Policy

Exposure estimate	Exposure rate (µg AI/lb handled) [a]	STADD (mg/kg/day) [b]
DPR estimate used in this Exposure Assessment (open cockpit) [c]	133	0.790
DPR's estimate if closed cockpit were required [d]	46.7	0.280
From PHED, according to U.S. EPA policy (closed cockpit) [e]	5.068	0.1312

[a] Total exposure rate, dermal plus inhalation, based on data in the Pesticide Handlers Exposure Database (PHED).
[b] Short-Term Absorbed Daily Dosage (STADD) estimates assumed an 8-hour workday. Amount treated was assumed by both DPR and U.S. EPA to be 350 acres (142 ha) treated/day (U.S. EPA, 2001). Body weight was assumed to be 70 kg by DPR (Thongsinthusak *et al*., 1993) and U.S. EPA (2002b).
[c] Department of Pesticide Regulation (DPR) use of PHED data described in Exposure Assessment section. Exposure rate and STADD are from Table 18. Estimates assumed open-cockpit aerial application, with applicator wearing respirator but not wearing gloves. Assumed application rate was 2.5 lbs AI/acre (2.8 kg AI/ha), maximum rate on tree nuts in California. Dermal absorption assumed to be 47.3% (Craine, 1988), and inhalation absorption assumed to be 100%.
[d] Estimate assumptions were the same as above, except that aerial applicators were assumed to use closed cockpit (no respirator use is assumed for closed cockpit). This estimate would be used by DPR if regulations or product labels specified a requirement for closed cockpits, which is not currently the case.
[e] U.S. Environmental Protection Agency (U.S. EPA) exposure estimates from Scenario 3 in revised exposure assessment (U.S. EPA, 2002b). Estimates assumed closed-cockpit aerial application, with applicator not wearing gloves or respirator. Assumed application rate was 3.0 lbs AI/acre (3.4 kg AI/ha), maximum rate on pecans; dermal and inhalation absorption factors were not used, as route-specific toxicity data were used in U.S. EPA's risk assessment.

<u>Nursery Stock Dipping Applicators</u>

Dermal exposure was estimated based on the RAGS-E model, which estimates skin permeability (K_p) to organic chemicals in aqueous solution (U.S. EPA, 2004a). There are many assumptions and uncertainties associated with this and other models that use K_p, some of which were discussed in U.S. EPA (2004a). Additional sources of uncertainty in models based on large and diverse data sets were discussed by Poda *et al.* (2001).

For endosulfan, an AI-specific K_p value was estimated based on an equation derived from a data set of about 200 organic compounds in aqueous solutions. The calculated K_p for endosulfan may be either over- or underestimated; there are not enough data available to be sure. As endosulfan is well within the range of MW and Log K_{ow} in which K_p

estimates are considered valid, based on Equations 3.9 and 3.10 in U.S. EPA (2004a), use of this equation is expected to result in a skin permeability estimate that correlates reasonably well with available data.

However, use of K_p with solutions of formulated pesticide products may result in exposure being underestimated, as the formulations contain additives (e.g., solvents, emulsifiers, and surfactants) to increase water solubility of AIs. Numerous studies have shown enhanced dermal penetration of chemicals, including pesticides, when mixed with such additives, as they can alter the barrier properties of the skin (Baynes and Riviere, 1998; Brand and Mueller, 2002; Williams and Barry, 2004). Alternately, flux into the skin could be decreased by additives in the formulation, as has been shown in some cases (Nielsen and Andersen, 2001; Riviere *et al.*, 2001), perhaps by altering how the chemical partitions between solution and skin (van der Merwe and Riviere, 2005). Exposure estimates could be improved if skin permeability measures were made using solutions of formulated products in concentrations that are pertinent to typical product use.

Another uncertainty from the use of K_p in estimating dermal exposure is that skin permeabilities are almost always estimated from *in vitro* rather than *in vivo* data. In an *in vitro* skin permeability test, a section of skin is clamped between two cells, called the "donor cell" and the "receptor cell." The donor solution (in the donor cell) contains the compound of interest; as the compound crosses the membrane it appears in the receptor solution, which is sampled periodically. A known concentration of compound is initially in the donor solution; the rate at which the compound concentration increases in the receptor solution is related to the skin permeability. Extrapolation from *in vitro* data to permeability of skin *in vivo* is problematic because relationships between *in vivo* and *in vitro* test results have not been reliably established for many classes of compounds, and dermal penetration have been shown to vary for compounds that have been tested (Wester and Maibach, 2000; Zendzian and Dellarco, 2003). Nevertheless, these models rely on the assumption that *in vitro* dermal penetration is approximately the same as *in vivo*.

Other assumptions common to these models are that the chemical concentration of water in contact with skin (C_w) is constant; and that absorbed dose is a function of solution concentration, skin permeability, and amount of exposed skin surface. These are reasonable assumptions, but have not been tested for solutions of pesticide products.

Another uncertainty existing in the RAGS-E model is related to the parameters τ and B. Calculations for these parameters rely on many assumptions and limited, surrogate data. The RAGS-E model has undergone some validation, but not with pesticides in formulated products (additives in the pesticide formulations may affect τ and B, as well as K_p).

Estimates of inhalation exposure for workers dipping nursery stock were based on SWIMODEL equations. SWIMODEL estimates pesticides concentrations in air based on conditions that may not be met in the nursery stock dipping scenario. In fact, substantial deviations occur from the assumptions on which the model is based. SWIMODEL relies on water-air partitioning to determine concentration of a chemical in air, using the Henry's Law constant for the chemical. However, Henry's Law constant applies to dilute, single-chemical aqueous solutions only. Staudinger and Roberts (2001) suggest 10,000 mg/L as an upper boundary defining a "dilute" solution under Henry's Law. This concentration is approached in the endosulfan dipping solution (6,000 mg/L). Furthermore, other chemicals present in the pesticide formulation can interact with the pesticide molecules, potentially affecting the partitioning of the AI into air (Staudinger and Roberts, 2001). Because the calculated concentration of AI in air was higher than anticipated at saturation, the estimated saturation concentration was used instead in inhalation exposure calculations; in other words, it was assumed that the AI is present at air-saturating concentrations. Because of this assumption, inhalation exposure is anticipated to be overestimated. In spite of this, the inhalation exposure estimate was substantially below the dermal exposure estimate, and the inhalation contribution to total exposure is considered negligible in this scenario.

In the absence of exposure monitoring or surrogate data, the results obtained from these models are considered the best estimate of dermal and inhalation exposure.

Other Defaults

PUR data were used to estimate likely numbers of days workers were exposed, based on the distribution of applications in high-use California counties. These high-use periods describe a recent work history of the handler population, and they probably overestimate the workdays for any single individual. However, they provide the best available data for seasonal and annual exposure estimates.

Additionally, the numbers of acres treated per day were based on defaults recommended by U.S. EPA (2001). These estimates are expected to be conservative but realistic; however, insufficient data exist to evaluate their accuracy.

Reentry Exposure Estimates

Acceptable monitoring data were lacking for fieldworker exposures. Exposure estimates for fieldworkers were appropriately based on chemical-specific DFR values; however, crop-specific DFR values were unavailable for most reentry scenarios. Because of this, DFR data from only four crops (grapes, lettuce, melons, and peaches) represented residues in all crops on which endosulfan may be used. The use of data from one crop to represent residues on another introduces uncertainties in exposure estimates. Residues may dissipate at different rates on different crops, due to factors such as leaf topography and physical and chemical properties of leaf surfaces.

The rate of contact with treated foliage, unlike DFR, is not chemical specific (U.S. EPA, 2000b). Transfer coefficient values for various crop activities are readily available, based on studies using other chemicals. Where activity- and crop-specific TCs were not available, defaults based on studies with similar activities and crops were used. These defaults were likely to be health-protective (U.S. EPA, 2000a).

Additionally, information is lacking about exposures resulting from some activities, such as weeding and roguing (removal of diseased crop plants) in cotton, and how these exposures might compare with those of scouts. Unlike other reentry workers, cotton harvesters work with plants which have been intentionally defoliated; DFR residues therefore cannot be used to estimate harvester exposures. The best available exposure estimate for weeders, roguers and harvesters in cotton is considered to be the estimate provided for cotton scouts. However, no data are available which would allow comparison of exposures between cotton scouts and those of other reentry workers in cotton.

Ambient Air and Bystander Exposure Estimates

Public exposures to airborne endosulfan were estimated based on concentrations of endosulfan in air and assumptions about uptake of endosulfan from the air. No biomonitoring or other exposure monitoring data were available. Exposure estimates were provided for adults for consistency with other scenarios, and for infants, as likely worst-case because infants have the greatest inhalation rate per body weight.

In air monitoring conducted by ARB (1998), samplers did not include filters to collect particulates. Evidence suggests that particulates have been trapped on XAD-2 resin in sampling tubes, as the top of the XAD sampling media has been found visibly darkened at the end of the sampling period (Baker, 2007). Additionally, paired samples collected during monitoring of another pesticide, azinphos-methyl, yielded similar results with and without 47-mm Gelman Teflon filters placed before the sorbent tubes (Seiber *et al.*, 1988). However, in the absence of filters, endosulfan adsorbed to particulates might not have been sampled quantitatively by ARB (1998), and as a result, airborne endosulfan available for inhalation (or deposition in the upper respiratory tract, which could then be swallowed) could potentially have been underestimated. The extent of such an underestimate is unclear, as the fraction of endosulfan in the particulate vs. gas phases can be expected to vary not only by vapor pressure of α- and β-endosulfan, but also by total suspended particulate concentrations and temperature (Sanusi *et al.*, 1999). In studies where endosulfan was reported separately from particulate and gas phases, inconsistent results were obtained. In some cases nearly all endosulfan was collected in the gas phase (e.g., Gioia *et al*., 2005; Li *et al*., 2007), while in others particle-bound endosulfan either equaled or exceeded amounts recovered from the gas phase (e.g., Scheyer *et al.*, 2005; Sun *et al*., 2006).

Further complicating this assessment, pesticides can be volatilized from filtered particles and transferred to sorbent during sampling, resulting in an underestimate of particle-sorbed fractions (Bidleman *et al.*, 1988; Sanusi *et al.*, 1999). Conversely, each of the four air monitoring studies in which endosulfan was quantified in both particulate and gas phases, poly-urethane foam (PUF) plugs were used to collect pesticides from the gas phase (Gioia *et al*., 2005; Scheyer *et al.*, 2005; Sun *et al*., 2006; Li *et al*., 2007). Dobson *et al*. (2006) found PUF less efficient in collecting endosulfan than XAD-2 resin, which suggests that endosulfan in the gas phase might have been underestimated in each of these studies. Existing data are not sufficient to quantitate any underestimate of concentration that might result from particle-bound endosulfan.

<u>Bystanders at Application Sites</u>

For bystander exposure estimates, the initial 24-hour TWA concentration from the east monitoring station, 6.4 m from the edge of the apple orchard where endosulfan was applied, was used as a reasonable worst-case estimate for endosulfan concentration in air for short-term exposure estimates. The 24-hour TWA was multiplied by a factor of 1.67 to account for the difference between the application rate monitored in the study and the maximum allowed application rate for endosulfan. This adjustment assumes that endosulfan concentrations in air are directly proportional to application rate.

Concentrations of endosulfan in air might be anticipated to vary with different application methods and with different types of crops. Factors affecting drift from spray applications include type of crop, wind velocity and direction, volume and direction of sprayer air jets and nozzles, and application rate (Frank *et al.*, 1994; SDTF, 1997; Fox *et al.*, 1998; Richards *et al*., 2001). Aerial and airblast applications typically result in greater spray drift than low-pressure boom applications, assuming similar spray droplet size and wind velocity (Frost and Ware, 1970; Frank *et al.*, 1994). To decrease the likelihood of underestimating exposures, application site results were corrected for field spike recoveries.

Seasonal and annual exposures to application site airborne endosulfan levels were estimated because endosulfan use is allowed up to six times per year on potatoes and tomatoes, suggesting that exposure durations greater than acute are possible for bystanders. However, occurrences of seasonal and annual bystander exposures are considered to have a low probability because airborne concentrations are anticipated to reach ambient levels within a few days after each application, and even individuals living near one or more application sites and working near others are unlikely to experience exposures above ambient for more than a few days. Airborne concentrations of active ingredients also decrease as distance from the application site increases (MacCollom *et al*., 1968; Siebers *et al.*, 2003), suggesting that it is unlikely that a person would be repeatedly exposed to elevated airborne concentrations in close succession that would result in a seasonal exposure. If fewer applications were allowed on potatoes and tomatoes, then the potential for seasonal and annual bystander exposures would be extremely remote. STADD estimates address exposures from less than one day up to 7 days.

Swimmer Exposure Estimates

Swimmer exposures to endosulfan in surface waters were estimated based on concentrations of endosulfan reported from surface water sampling and assumptions about uptake of endosulfan from water. No biomonitoring or other exposure monitoring data were available. Exposure estimates were provided for adults for consistency with other scenarios, and for children, as likely worst-case because children have relatively greater surface area exposed to the water, per body weight, than adults.

Endosulfan concentrations used to calculate swimmer exposure estimates were derived from DPR's Surface Water Database. This database contains data reported from a variety of environmental monitoring studies targeting pesticides. These studies were conducted by several agencies, had different detection limits, and different study designs. Sampling frequency and sample collection site varied, and it is possible that the highest endosulfan concentrations were not reflected in the samples collected. If so, then short-term exposures may be underestimated. Some studies monitored irrigation drains, which would be anticipated to have higher concentrations than rivers, for example (although the highest reported concentrations occurred in samples collected from rivers). The collection sites chosen for environmental monitoring might also be biased toward those where pesticides are most likely to occur; if so, the median concentrations used to calculate long-term exposures may be overestimated.

The effectiveness of permit conditions instituted in 1991 by DPR, and incorporated into product labels, has not been assessed. DPR (1994) contains endosulfan data from sampling done between 1990 and 1996. No trend of decreasing endosulfan concentrations since 1991 is evident from these data (the last sample, collected July 22, 1996, had a total endosulfan concentration of 0.122 µg/L).

Swimmer exposures were estimated based on equations and defaults for swimmers in treated swimming pools (U.S. EPA, 2003). The relevance of the assumptions underlying these calculations for swimmers in surface waters, rather than swimming pools, is unknown. No information is available for frequency or duration of swimming in surface waters (as opposed to community or residential swimming pools).

REFERENCES

Abalis, I.M., Eldefrawi, M.E. and Eldefrawi, A.T. 1986. Effects of insecticides on GABA induced chloride influx into rat brain microsacs. Journal of Toxicology and Environmental Health 18:13-23.

Agrawal, A.K., Anand, M., Zaidi, N.F. and Seth, P.K. 1983. Involvement of serotonergic receptors in endosulfan neurotoxicity. Biochemical Pharmacology 32:3591-3593

Air Resources Board (ARB). 1998. Report for the Air Monitoring of Endosulfan in Fresno County (Ambient) and in San Joaquin County (Application). Project No. C96-034. Sacramento, CA: Engineering and Laboratory Branch, Air Resources Board, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/empm/pubs/tac/endoslfn.htm

Andrews, C.M. 2000. Worker Health and Safety Branch Policy on the Statistical Analysis for Dislodgeable Foliar Residue Data. Memo No. HSM-00011, dated February 4. Sacramento, CA: California Department of Pesticide Regulation, Worker Health and Safety Branch. http://www.cdpr.ca.gov/docs/whs/memo/hsm00011

Andrews, C. and Patterson, G. 2000. Interim Guidance for Selecting Default Inhalation Rates for Children and Adults. Memo No. HSM-00010, dated December 1. Sacramento, CA: California Department of Pesticide Regulation, Worker Health and Safety Branch. http://www.cdpr.ca.gov/docs/whs/memo/hsm00010

Aprea, C., Sciarra, G., Sartorelli, P., Desideri, E., Amati, R. and Sartorelli, E. 1994. Biological monitoring of exposure to organophosphorus insecticides by assay of urinary alkylphosphates: Influence of protective measures during manual operations with treated plants. International Archives of Occupational and Environmental Health 66:333-338.

Arrebola, F.J., Martinez Vidal, J.L. and Fernandez-Gutierrez, A. 1999. Excretion study of endosulfan in urine of a pest control operator. Toxicology Letters 107:15-20.

Arrebola, F.J., Martinez Vidal, J.L. and Fernandez-Gutierrez, A. 2001. Analysis of endosulfan and its metabolites in human serum using gas chromatography – tandem mass spectrometry. Journal of Chromatographic Science 39:177-182.

Baker, L. 2007. Re: Proposed text for endosulfan appraisal section (particulates). E-mail to Sheryl Beauvais, Staff Toxicologist (Specialist), Worker Health and Safety Branch, Department of Pesticide Regulation, from Lynton Baker, Stationary Source Division, Air Resources Board, dated November 2, 2007. Sacramento, CA: Air Resources Board, California Environmental Protection Agency.

Baugher, D.G. 1989. Exposure of Mixer/Loader/Applicators to Thiodan® 3EC Insecticide Applied to Fruit Trees by Airblast Equipment in California, 1987. Unpublished study submitted by Hoechst Celanese Corporation, Lab Project No. 24587. DPR Data Volume 182-060, Record No. 73677.

Baynes, R.E. and Riviere, J.E. 1998. Influence of inert ingredients in pesticide formulations on dermal absorption of carbaryl. American Journal of Veterinary Research 59:168-175.

Beauvais, S.L. 2004. Nursery Stock Root Dips: Applicator Exposure Estimates. Memo No. HSM-04029, dated December 24. Sacramento, CA: California Department of Pesticide Regulation, Worker Health and Safety Branch.

Beauvais, S.L. 2006. Review of Carbaryl Airblast Exposure Monitoring and Sock Dosimetry Analytical Method Validation Studies, Data Packages 210452 and 213826s. Memo No. HSM-06002, dated February 24. Sacramento, CA: California Department of Pesticide Regulation, Worker Health and Safety Branch.

Beech, JA. 1980. Estimated worst case trihalomethane body burden of a child using a swimming pool. Medical Hypotheses 6:303-307.

Bidleman, T.F. 1988. Atmospheric processes. Environmental Science and Technology 22:361-367.

Brand, R.M. and Mueller, C. 2002. Transdermal penetration of atrazine, alachlor, and trifluralin: Effect of formulation. Toxicological Sciences 68:18-23.

Brandt, V.A., Moon, S., Ehlers, J., Methner, M.M. and Struttmann, T. 2001. Exposure to endosulfan in farmers: Two case studies. American Journal of Industrial Medicine 39:643-649.

Brodberg, R.K. and Pollock, G.A. 1999. Prevalence of Selected Target Chemical Contaminants In Sport Fish from Two California Lakes: Public Health Designed Screening Study. Sacramento, CA: Office of Environmental Health Hazard Assessment, California Environmental Protection Agency.

Bunge, A.L. and Cleek, R.L. 1995. A new method for estimating dermal absorption from chemical exposure: 2. Effect of molecular weight and octanol-water partitioning. Pharmaceutical Research 12:88-95.

Bunge, A.L., Cleek, R.L. and Vecchia, B.E. 1995. A new method for estimating dermal absorption from chemical exposure. 3. Compared with steady-state methods for prediction and data analysis. Pharmaceutical Research 12:972-982.

Burgoyne, T.W. and Hites, R.A. 1993. Effects of temperature and wind direction on the atmospheric concentrations of α-endosulfan. Environmental Science and Technology 27:910-914.

Casabar, R.C., Wallace, A.D., Hodgson, E. and Rose, R.L. 2006. Metabolism of endosulfan-alpha by human liver microsomes and its utility as a simultaneous in vitro probe for CYP2B6 and CYP3A4. Drug Metabolism and Disposition 34:1779-1785.

Casida, J.E. and Lawrence, L.J. 1985. Structure-activity correlations for interactions of bicyclophosphorus esters and some polychlorocycloalkane and pyrethroid insecticides with the brain-specific t-butylbicyclophosphorothionate receptor. Environmental Health Perspectives 61:123-132.

Chaisson, C.F., Sielken, R.L., Jr. and Waylett, D.K. 1999. Overestimation bias and other pitfalls associated with the estimated 99.9th percentile in acute dietary exposure assessments. Regulatory Toxicology and Pharmacology 29:102-127.

Chan, M.P., Morisawa, S., Nakayama, A., Kawamoto, Y., Sugimoto, M. and Yoneda, M. 2005. Toxicokinetics of ^{14}C-endosulfan in male Sprague-Dawley rats following oral administration of single or repeated doses. Environmental Toxicology 20:533-541.

Cole, L.M. and Casida, J.E. 1986. Polychlorocycloalkane insecticide-induced convulsions in mice in relation to disruption of the GABA-regulated chloride ionophore. Life Sciences 39:1855-1862.

Craine, E.M. 1988. A Dermal Absorption Study in Rats with ^{14}C-Endosulfan with Extended Test Duration. Unpublished study submitted by Hoechst Celanese Corporation, Lab Project No. WIL 39029. DPR Registration Document 182-060, Record No. 73769.

Dawson, J.L. 2003. Human Health Risk Assessment: Carbaryl. Washington, DC: Health Effects Division, Office of Pesticide Programs, U.S. Environmental Protection Agency.

Dobson, R., Scheyer, A., Rizet, A.L., Mirabel, P. and Millet, M. 2006. Comparison of the efficiencies of different types of adsorbents at trapping currently used pesticides in the gaseous phase using the technique of high-volume sampling. Analytical and Bioanalytical Chemistry 386:1781-1789.

Dong, M.H. 1990. Dermal Transfer Factor for Cotton Scouts. Memo No. HSM-90001, dated June 8. Sacramento, CA: Worker Health and Safety Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/whs/memo/hsm90001

Dorough, H.W., Huhtanen, K., Marshall, T.C. and Bryant, H.E. 1978. Fate of endosulfan in rats and toxicological considerations of apolar metabolites. Pesticide Biochemistry and Physiology 8:241-252.

DPR. 2001. Summary of Pesticide Use Report Data 2000: Indexed by Chemical. Report dated October 2001. Sacramento, CA: Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/pur/pur00rep/chmrpt00.pdf

DPR. 2002. Summary of Pesticide Use Report Data 2001: Indexed by Chemical. Report dated October 2002. Sacramento, CA: Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/pur/pur01rep/chmrpt01.pdf

DPR. 2003. Summary of Pesticide Use Report Data 2002: Indexed by Chemical. Report dated October 2003. Sacramento, CA: Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/pur/pur02rep/chmrpt02.pdf

DPR. 2004. Surface Water Database Complete Chemical Analysis Results. Downloadable data files updated January 2004, accessed June 8, 2005. Website to download files: http://www.cdpr.ca.gov/docs/sw/surfcont.htm

DPR. 2005. Summary of Pesticide Use Report Data 2003: Indexed by Chemical. Report dated January 2005. Sacramento, CA: Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/pur/pur03rep/chmrpt03.pdf

DPR. 2006a. California Pesticide Information Portal (CalPIP), Pesticide Use Report database. Website accessed for database queries on several dates. Sacramento, CA: Department of Pesticide Regulation, California Environmental Protection Agency. http://calpip.cdpr.ca.gov/cfdocs/calpip/prod/main.cfm

DPR. 2006b. Summary of Pesticide Use Report Data 2004: Indexed by Chemical. Report dated January 2006. Sacramento, CA: Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/pur/pur04rep/chmrpt04.pdf

DPR. 2006c. Summary of Pesticide Use Report Data 2005: Indexed by Chemical. Report dated November 2006. Sacramento, CA: Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/pur/pur05rep/chmrpt05.pdf

DPR. 2007. Report of Pesticides Sold in California: 2005. Report dated June 13. Sacramento, CA: Department of Pesticide Regulation. http://www.cdpr.ca.gov/docs/mlassess/nopdsold.htm

Durham, W.F. and Wolfe, H.R. 1962. Measurement of the exposure of workers to pesticides. Bulletin of the WHO 26:75-91.

Edmiston, S., Cowan, C. and Welsh, A. 1999. California Farm Worker Activity Profile: A Database of Farm Worker Activity Demographics. Report No. HS-1751. Sacramento, CA: Worker Health and Safety Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/whs/pdf/hs1751.pdf.

Estesen B.J., Buck, N.A. and Ware, G.W. 1979. Dislodgeable insecticide residues on cotton foliage: permethrin, curacron, fenvalerate, sulprofos, decis, and endosulfan. Bulletin of Environmental Contamination and Toxicology 22:245-248.

Fellers, G.M., McConnell, L.L., Pratt, D. and Datta, S. 2004. Pesticides in mountain yellow-legged frogs (*Rana muscosa*) from the Sierra Nevada Mountains of California, USA. Environmental Toxicology and Chemistry 23:2170-2177.

Ffrench-Constant, R.H., Anthony, N., Aronstein, K., Rocheleau, T. and Stilwell, G. 2000. Cyclodiene insecticide resistance: from molecular to population genetics. Annual Review of Entomology 48:449-466.

Fleck, J., Ross, L., Tran, D., Melvin, J. and Fong, B. 1991. Off-target movement of endosulfan from artichoke fields in Monterey County. Report No. EH 91-05. Sacramento, CA: California Department of Pesticide Regulation, Environmental Monitoring and Pest Management Branch. Available at: http://www.cdpr.ca.gov/docs/empm/pubs/ehapreps/eh9105.pdf.

Fox, R.D., Derksen, R.C. and Brasee, R.D. 1998. Airblast/Air-assisted application equipment and drift. In: Proceedings of the North American Conference on Pesticide Spray Drift Management. March 29–April 1, 1998. Holiday Inn By the Bay, Portland Maine. Sponsored by the Maine Board of Pesticide Control and the University of Maine Cooperative Extension Pest Management Office. Donna Buckley, Editor. http://pmo.umext.maine.edu/drift/drift proceedings.pdf

Frank, R., Ripley, B.D., Lampman, W., Morrow, D., Collins, H., Gammond, G.R. and McCubbin, P. 1994. Comparative spray drift studies of aerial and ground applications 1983–1985. *Environ. Monit. Assess.* 29:167-181.

Frost, K.R. and Ware, G.W. 1970. Pesticide drift from aerial and ground applications. Agricultural Engineering 51: 460-464.

Ganapathy, C., Nordmark, C., Bennett, K., Bradley, A., Feng, H., Hernandez, J. and White, J. 1997. Temporal Distribution of Insecticide Residues in Four California Rivers. Report No. EH 97-06. Sacramento, CA: California Department of Pesticide Regulation, Environmental Monitoring and Pest Management Branch. Available at: http://www.cdpr.ca.gov/docs/empm/pubs/ehapreps/eh976rep.pdf.

Gioia, R., Offenberg, J. H., Gigliotti, C. L., Totten, L. A., Du, S. Y. and Eisenreich, S. J. 2005. Atmospheric concentrations and deposition of organochlorine pesticides in the US Mid-Atlantic region. Atmospheric Environment 39:2309-2322.

Gonzalez, D., Ross, L.J., Segawa, R. and Fong, B. 1987. Variation of Endosulfan Residues in Water and Sediment Taken from the Moss Landing Drainage of Monterey County. Report EH 87-02. Sacramento, CA: Environmental Monitoring Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/empm/pubs/ehapreps/eh8702.pdf.

Grover, R., Cessna, A.J., Muir, N.I., Riedel, D., Franklin, C.A. and Yoshida, K. 1986. Factors affecting the exposure of ground-rig applicators to 2,4-D dimethylamine salt. Archives of Environmental Contamination and Toxicology 15:677-686.

Guo, L. and Spurlock, F. 2000. Recommendation for Priority Surface Water Monitoring Studies on Selected Pesticides. Memorandum dated August 2. Sacramento, CA: Environmental Monitoring Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/empm/pubs/ehapreps/m080200.pdf

Gupta, P.K. and Ehrnebo, M. 1979. Pharmacokinetics of α- and β-isomers of racemic endosulfan following intravenous administration in rabbits. Drug Metabolism and Disposition 7:7-10.

Hahn, G.J. and Meeker, W.Q. 1991. Statistical Intervals: A Guide for Practitioners. New York, John Wiley & Sons, Inc.

Haskell, D.E. 1998. Canada-United States Trade Agreement (CUSTA) Working Group, Final Draft of Position Paper for Issue Eight: Typical Workdays for Various Crops. Memo No. HSM-98001. Sacramento, CA: Worker Health and Safety Branch, Department of Pesticide Regulation, California Environmental Protection Agency.

Hatzilazarou S.P., Charizopoulos, E.T., Papadopoulou-Mourkidou, E. and Economou, A.S. 2004. Dissipation of three organochlorine and four pyrethroid pesticides sprayed in a greenhouse environment during hydroponic cultivation of gerbera. Pest Management Science 60:1197-1204.

Hernandez, B.Z., Spencer, J., Schneider, F., Welsh, A and Fredrickson, S. 1998. A Survey of Dislodgeable Pesticide Residues on Crop Foliage at Field Reentry, 1994-1995. Report No. HS-1728. Sacramento, CA: Worker Health and Safety Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/whs/pdf/hs1728.pdf.

Hernandez, B.Z., Spencer, J., Schneider, F., Welsh, A and Fredrickson, S. 2002. A Summary of Dislodgeable Foliar Pesticide Residues at Expiration of the Restricted Entry Interval. Report No. HS-1784. Sacramento, CA: Worker Health and Safety Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/whs/pdf/hs1784.pdf

Hines, C.J., Deddens, J.A., Tucker, S.P. and Hornung, R.W. 2001. Distributions and determinants of pre-emergent herbicide exposures among custom applicators. Annals of Occupational Hygiene 45:227-239.

Iwata, Y., Knaak, J.B., Spear, R.B. and Foster, R.J. 1977. Worker reentry into pesticide treated crops. I. Procedure for the determination of dislodgeable pesticide residues on foliage. Bulletin of Environmental and Contamination Toxicology 18:649.

Kennedy, I.R., Sánchez-Bayo, F., Kimber, S.W., Hugo, L. and Ahmad, N. 2001. Off-site movement of endosulfan from irrigated cotton in New South Wales. Journal of Environmental Quality 30:683-696.

Klonne, D.R., Fuller, R. and Howell, C. 2000. Determination of Dermal and Inhalation Exposure to Reentry Workers During Harvesting in Nursery Stock. Unpublished study submitted by the Agricultural Reentry Task Force. ARTF Study ARF044. DPR Data Volume 50366-176, Record No. 181586.

Lachman, G. 1987. Dermal Absorption of ^{14}C-Endosulfan in Rhesus Monkeys. Unpublished study submitted by Hoechst Celanese Corporation, Lab Project No. BIEV-V-66.697. DPR Data Volume 182-060, Record No. 73678.

Lawrence, L.J. and Casida, J.E. 1984. Interactions of lindane, toxaphene and cyclodienes with brain specific t-butylcyclophosphorothionate receptor. Life Sciences 35:171-178.

Layton, D.W. 1993. Metabolically consistent breathing rates for use in dose assessments. Health Physics 64:23-36.

Lee, H.K., Moon, J.K., Chang, C.H., Choi, H., Park, H.W., Park, B.S., Lee, H.S., Hwang, E.C., Lee, Y.D., Liu, K.H. and Kim, J.H. 2006. Stereoselective metabolism of endosulfan by human liver microsomes and human cytochrome P450 isoforms. Drug Metabolism and Disposition 34:1090-1095.

LeNoir, J.S., McConnell, L.L., Fellers, G.M., Cahill, T.H. and Seiber, J.N. 1999. Summertime transport of current-use pesticides from California's Central Valley to the Sierra Nevada mountain range. Environmental Toxicology and Chemistry 18:2715-2722.

Li, J., Zhang, G., Guo, L. L., Li, X. D., Lee, C. S. L., Ding, A. J. and Wang, T. 2007. Organochlorine pesticides in the atmosphere of Guangzhou and Hong Kong: Regional sources and long range atmospheric transport. Atmospheric Environment 41:3889-3903.

Lonsway, J.A., Byers, M.E., Dowla, H.A., Panemangalore, M. and Atonious, G.F. 1997. Dermal and respiratory exposure of mixers/sprayers to acephate, methamidophos, and endosulfan during tobacco production. Bulletin of Environmental Contamination and Toxicology 59:179-186.

MacCollom, G.B., Johnston, D.B. and Parker, B.L. 1968. Determination and measurement of dust particles in atmospheres adjacent to orchards. Bulletin of Environmental Contamination and Toxicology 3:368-374.

MacNeil, J.D. and Hikichi, M. 1976. Degradation of endosulfan and ethion on pear and grape foliage. Journal of Agricultural and Food Chemistry 24:608-611.

Maddy, K.T., Shimer, D.A., Smith, C.R., Kilgore, S.L., Quan, V., Margetich, S. and Cooper, C. 1985a. A Degradation Study of Dislodgeable Endosulfan (Thiodan) Residues on Row Crops in Fresno and San Luis Obispo Counties During June 1984. Report no. HS-1263. Sacramento, CA: Worker Health and Safety Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/whs/pdf/hs1263.pdf

Maddy, K.T., Edmiston, S. and Cooper, C. 1985b. Degradation of Dislodgeable Foliar Residues of Endosulfan on Chinese Cabbage. Report no. HS-1312. Sacramento, CA: Worker Health and Safety Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/whs/pdf/hs1312.pdf

Martinez Vidal, J.L., Arrebola, F.J., Fernandez-Gutierrez, A. and Rams, M.A. 1998. Determination of endosulfan and its metabolites in human urine using gas chromatography – tandem mass spectrometry. Journal of Chromatography B719:71-78.

Mehler, L. 2007. Case Reports Received by the California Pesticide Illness Surveillance Program, 1992 – 2005 in Which Health Effects Were Evaluated as Definitely, Probably, or Possibly Related to Exposure to Endosulfan, Alone or in Combination. Pesticide Illness Surveillance Program custom database query, Worker Health and Safety Branch, Department of Pesticide Regulation, California Environmental Protection Agency.

NAAA. 2004. Pesticide Use Survey Report for Agricultural Aviation: A Study Conducted by the National Agricultural Aviation Association (NAAA). Unpublished report dated May 2004.

Nielsen, J.B. and Andersen, H.R. 2001. Dermal in vitro penetration of methiocarb, paclobutrazol, and pirimicarb: Effect of nonylphenolethoxylate and protective gloves. Environmental Health Perspectives 109:129-132.

NIOSH. 1987. Respirator Decision Logic. Washington, D.C.: National Institute for Occupational Safety and Health, U.S. Department of Health and Human Services.

OEHHA. 2000. Air Toxics Hot Spots Program Part IV: Technical Support Document. Exposure Assessment and Stochastic Analysis. Scientific Review Panel Draft. Sacramento, CA:. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency. http://www.oehha.ca.gov/air/hot_spots/finalStoc.html#download

Okumura, D.Y. 1991. Suggested Criteria for Issuance of Endosulfan Permits and Suggested Permit Conditions. Letter No. ENF 91-12 to County Agricultural Commissioners from Douglas Y. Okumura, Chief, Pesticide Enforcement Branch, DPR, dated January 29. Sacramento, CA: Department of Pesticide Regulation, California Environmental Protection Agency.

Okumura, D.Y. 1992. Development of Endosulfan Regulations. Letter No. ENF 92-10 to County Agricultural Commissioners from Douglas Y. Okumura, Chief, Pesticide Enforcement Branch, DPR, dated January 31. Sacramento, CA: Department of Pesticide Regulation, California Environmental Protection Agency.

Peterson, S.M. and Batley, G.E. 1993. The fate of endosulfan in aquatic ecosystems. Environmental Pollution 82:143-152.

PHED. 1995. The Pesticide Handlers Exposure Database, Version 1.1. Prepared for the PHED Task Force representing Health and Welfare Canada, U.S. Environmental Protection Agency, and the National Agricultural Chemicals Association; prepared by Versar, Inc., 6850 Versar Center, Springfield, VA 22151.

Poda, G.I., Landsittel, D.P., Brumbaugh, K., Sharp, D.S., Frasch, H.F. and Demchuk, E. 2001. Random sampling or 'random' model in skin flux measurements? [Commentary on "Investigation of the mechanism of flux across human skin in vitro by quantitative structure-permeability relationships"]. European Journal of Pharmaceutical Sciences 14:197-200.

Powell, S. 2002. Approximating Confidence Limits for Upper Bound and Mean Exposure Estimates from the Pesticide Handlers Exposure Database (PHED V1.1). Memo No. HSM-02037, dated September 27. Sacramento, CA: Worker Health and Safety Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/whs/memo/hsm02037

Powell, S. 2003. Why Worker Health And Safety Branch Uses Arithmetic Means in Exposure Assessment. HSM-03022, dated September 22. Sacramento, CA: California Department of Pesticide Regulation, Worker Health and Safety Branch.

Rech, C. and Edmiston, S. 1988. A General Survey of Foliar Residues and Air Concentration Levels Following Various Greenhouse Applications, 1986. Report no. HS-1403. Sacramento, CA: Worker Health and Safety Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/whs/pdf/hs1403.pdf.

Reinert, J.C., Nielsen, A.P., Lunchick, C., Hernandez, O. and Mazzetta, D.M. 1986. The United States Environmental Protection Agency's guidelines for applicator exposure monitoring. Toxicology Letters 33:183-191.

Rice, C., Nochetto, C. and Zara, P. 2002. Volatilization of trifluralin, atrazine, metolachlor, chlorpyrifos, α-endosulfan and β-endosulfan from freshly tilled soil. Journal of Agricultural and Food Chemistry 50:4009-4017.

Richards, S.M., McClure, G.Y., Lavy, T.L., Mattice, J.D., Keller, R.J. and Gandy, J. 2001. Propanil (3,4-dichloropropionanilide) particulate concentrations within and near the residences of families living adjacent to aerially sprayed rice fields. Archives of Environmental and Contamination Toxicology 41:112-116.

Riviere, J.E., Qiao, G., Baynes, R.E., Brooks, J.D. and Mumtaz, M. 2001. Mixture component effects on the in vitro dermal absorption of pentachlorophenol. Archives of Toxicology 75:329-334.

Robinson, R.A. 1987. Henry's Law Constant - Calculated Estimates of Water Volatility for Carbofuran, Permethrin, Endosulfan and Metiram. Unpublished study submitted by FMC Corporation, Philadelphia, PA. FMC Project No. 078E60M01. DPR Data Volume 182-053, Record No. 59755.

Ross, L.J., Stein, R., Hsu, J., White, J. and Hefner, K. 1996. Distribution and Mass Loading of Insecticides in the San Joaquin River, California: Winter 1991-92 and 1992-93. Report No. EH 96-02. Sacramento, CA: Environmental Monitoring and Pest Management Branch. Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/empm/pubs/ehapreps/eh9602.pdf

Ross, L.J., Stein, R., Hsu, J., White, J. and Hefner, K. 1999. Insecticide Concentrations in the San Joaquin River, California: Spring 1991 and 1992. Report No. EH 99-01. Sacramento, CA: Environmental Monitoring and Pest Management Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/empm/pubs/ehapreps/eh9901.pdf

Ross, L.J., Stein, R., Hsu, J., White, J. and Hefner, K. 2000. Insecticide Concentrations in the San Joaquin River, California: Summer 1991 and 1992. Report No. EH 00-09. Sacramento, CA: Environmental Monitoring and Pest Management Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/empm/pubs/ehapreps/eh0009.pdf

Rutz, R. 1997. A History of the Listing of Pesticides as Restricted Materials in California. Report No. HS-1669. Sacramento, CA: Worker Health and Safety Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/whs/pdf/hs1669.pdf

Rutz. R. and Krieger, R.I. 1992. Exposure to pesticide mixer/loaders and applicators in California. Reviews of Environmental Contamination and Toxicology 129:121-139.

Sanders, J.S. 1997. Monitoring Recommendation for Endosulfan. Memorandum to George Lew, Chief, Engineering and Laboratory Branch, Air Resources Board, dated September 22. Available as Appendix V of the Report for the Air Monitoring of Endosulfan in Fresno County (Ambient) and in San Joaquin County (Application). Project No. C96-034. Sacramento, CA: Engineering and Laboratory Branch, Air Resources Board, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/empm/pubs/tac/tacpdfs/endosapa.pdf

Sanusi, A., Millet, M., Mirabel, P. and Wortham, H. 1999. Gas-particle partitioning of pesticides in atmospheric samples. Atmospheric Environment 33:4941-4951.

Sarafin, R. 1979a. Hoe 052618 and Hoe 052619 (α- and β-Endosulfan) Solubility in Water. Unpublished study submitted by FMC Corporation, Philadelphia, PA. Report No. (B)154/87. DPR Data Volume 182-056, Record No. 63585.

Sarafin, R. 1979b. Hoe 052618 and Hoe 052619 (α- and β-Endosulfan) Partition Coefficient Octanol/Water. Unpublished study submitted by FMC Corporation, Philadelphia, PA. Report No. (B)124/87. DPR Data Volume 182-056, Record No. 63586.

Sarafin, R. 1982. Hoe 002671 (Endosulfan), Hoe 052618 (α-Endosulfan) and Hoe 052619 (β-Endosulfan) – Vapor Pressure. Unpublished study submitted by FMC Corporation, Philadelphia, PA. Report No. (B)153/87. DPR Data Volume 182-056, Record No. 63587.

SAS. 2003. SAS 9.1. SAS Institute, Inc., Cary, NC.

Sava, R.J. 1985. Monterey County Residential Air Monitoring. Report No. EH 85-07. Sacramento, CA: Environmental Monitoring Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/empm/pubs/ehapreps/eh8507.pdf.

Schmidt, W.F., Bilboulian, S., Rice, C.P., Fettinger, J.C., McConnell, L.L. and Hapeman, C.J. 2001. Thermodynamic, spectroscopic, and computational evidence for the irreversible conversion of β- to α-endosulfan. Journal of Agricultural and Food Chemistry 49:5372-5376.

Schuette, J., Weaver, D., Troiano, J., Pepple, M. and Dias, J. 2003. Sampling for Pesticide Residues in California Well Water: 2003 Well Inventory Database, Cumulative Report 1986-2003. Report No. EH03-08. Sacramento, CA: Environmental Monitoring Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/empm/pubs/ehapreps/eh0308.pdf

SDTF. 1997. A Summary of Airblast Application Studies. Spray Drift Task Force (SDTF). Stewart Agricultural Research Services, Inc. Macon, MO. http://www.agdrift.com/PDF_FILES/airblast.pdf

Seiber, J.N., McChesney, M.M., Woodrow, J.E. and Shibamoto, T.S. 1988. Final Report to the Air Resources Board: Pilot Analysis of Azinphos-Methyl in Air: Contract # A5-169-43. Report date January 4, 1988. Department of Environmental Toxicology, University of California, Davis. http://www.cdpr.ca.gov/docs/emon/pubs/tac/tacpdfs/azm_amb.pdf

Siebers, J., Binner, R. and Wittich, K.P. 2003. Investigation on downwind short-range transport of pesticides after application in agricultural crops. Chemosphere 51:397-407.

Silva, M. 2004. Summary of Toxicological Data. Endosulfan. Chemical Code #259. Sacramento, CA: Medical Toxicology Branch, Department of Pesticide

Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/toxsums/pdfs/259.pdf

Singer, S.S. 1997. Dissipation of Foliar Dislodgeable Residues for Endosulfan Following Application of Phaser® WP and Phaser® EC to Melons, Peaches and Grapes, USA 1995. Unpublished study submitted by AgrEvo USA, Lab Project No. BJ-95R-01. DPR Data Volume 182-105, Record No. 162454.

Singhasemanon, N. 1995. Review of the Toxic Substances Monitoring Program's 1993-1994 Preliminary Data Report. Memo dated October 16. Sacramento, CA: Environmental Monitoring and Pest Management Branch, Department of Pesticide Regulation, California Environmental Protection Agency.

Singhasemanon, N. 1996. Review of the State Mussel Watch 1995 Survey Preliminary Data Report. Memo dated August 30. Sacramento, CA: Environmental Monitoring and Pest Management Branch, Department of Pesticide Regulation, California Environmental Protection Agency.

Smith, L.D. 2005. Amended Report: Determination of Dermal and Inhalation Exposure to Workers During Application of a Liquid Pesticide Product by Open Cab Airblast Application to Orchard Crops. Study Number AHE07, dated August 23. Unpublished study submitted by Agricultural Handlers Exposure Task Force. DPR Data Volume 108-340, Record No. 219609.

Sparling, D.W., Fellers, G.M. and McConnell, L.L. 2001. Pesticides and amphibian population declines in California, USA. Environmental Toxicology and Chemistry 20:1591-1595.

Spear, R.C. and Popendorf, W.J. 1976. The Role of Foliar Particulate Matter in the Degradation of the Dislodgeable Foliar Residues of the Organophosphate Pesticides. Technical Report Contract 4277 to the California State Department of Food and Agriculture. Report No. ACF 59-267. http://www.cdpr.ca.gov/docs/whs/pdf/hs267.pdf

Srikanth, NS., Seth, P.K. and Desaiah, D. 1989. Inhibition of calmodulin activated Ca^{+2} ATPase by endosulfan in rat brain. Journal of Toxicology and Environmental Health 28:473-481.

Staudinger, J. and Roberts, P.V. 2001. A critical compilation of Henry's law constant temperature dependence relations for organic compounds in dilute aqueous solutions. Chemosphere 44:561-576.

Sun, P., Blatnchard, P., Brice, K. and Hites, R.A. 2006. Atmospheric organochlorine pesticide concentrations near the Great Lakes: temporal and spatial trends. Environmental Science and Technology 40:6587-6593.

Sutherland, T.D., Home, I., Weir, K.M., Russell, R.J. and Oakeshott, J.G. 2004. Toxicity and residues of endosulfan isomers. Reviews in Environmental Contamination and Toxicology 183:99-113.

Thompson, R. 1998. Agricultural Worker Contact from Reentry Activities Performed in the United States and Canada: Grower Results. Unpublished study submitted by the Agricultural Reentry Task Force. Performed by Doane Marketing Research, Inc., St. Louis, MO. DPR Volume Number 52062-314.

Thongsinthusak, T., Brodberg, R. K., Ross, J. H., Gibbons, D. and Krieger, R. I. 1991. Reduction of Pesticide Exposure by Using Protective Clothing and Enclosed Cabs. HS-1616. Sacramento, CA: Worker Health and Safety Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/whs/pdf/hs1616.pdf

Thongsinthusak, T., Ross, J. and Meinders, D. 1993. Guidance for the Preparation of Human Pesticide Exposure Assessments. Report no. HS-1612. Sacramento, CA: Worker Health and Safety Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/whs/pdf/hs1612.pdf

Tomlin, C.D.S. (editor). 1994. The Pesticide Manual, 10th Edition. British Crop Protection Council and The Royal Society of Chemistry, United Kingdom. The Bath Press, Bath.

Troiano, J., Weaver, D., Marade, J., Spurlock, F., Pepple, M., Nordmark, C. and Bartkowiak, D. 2001. Summary of well water sampling in California to detect pesticide residues resulting from nonpoint-source applications. Journal of Environmental Quality 30:448-459.

University of California Cooperative Extension (UCCE). 2004. Available Cost and Return Studies. Department of Agricultural and Resource Economics. Website accessed for crop-specific information from September through November 2004. http://www.agecon.ucdavis.edu

USDA. 2003. Lamont, M. and Epstein, R.C., eds. Pesticide Data Program (PDP) Annual Summary Calendar Year 2001, U.S. Department of Agriculture. Agricultural Marketing Service, Washington, D.C.

USDA. 2004. Lamont, M. and Epstein, R.C., eds. Pesticide Data Program (PDP) Annual Summary Calendar Year 2002, U.S. Department of Agriculture. Agricultural Marketing Service, Washington, D.C.

USDA. 2005. Lamont, M. and Epstein, R.C., eds. Pesticide Data Program (PDP) Annual Summary Calendar Year 2003, U.S. Department of Agriculture. Agricultural Marketing Service, Washington, D.C.

U.S. EPA. 1992. Dermal Exposure Assessment: Principles and Applications. EPA/600/8-91/011B. Washington, DC: Office of Health and Environmental Assessment, United States Environmental Protection Agency.

U.S. EPA. 1996. Occupational and Residential Exposure Test Guidelines. OPPTS 875.2100: Foliar Dislodgeable Residue. 712-C-96-267. Washington, DC: Office of Prevention, Pesticides and Toxic Substances, U.S. Environmental Protection Agency.

U.S. EPA. 1997. Exposure Factors Handbook. EPA/600/P-95/002Fa. Washington, D.C.: Office of Research and Development, U.S. Environmental Protection Agency. http://www.epa.gov/ncea/pdfs/efh/front.pdf

U.S. EPA. 1998a. PHED Surrogate Exposure Guide. Estimates of Worker Exposure from the Pesticide Handler Exposure Database, Version 1.1. Washington, DC: Office of Prevention, Pesticides and Toxic Substances, U.S. Environmental Protection Agency.

U.S. EPA. 1998b. The Use of PHED Aerial Application Data. Policy Number 006, Science Advisory Council for Exposure. Dated August 12.

U.S. EPA. 1998c. Health Effects Test Guidelines. Health Effects Test Guidelines: Dermal Penetration (OPPTS 870.7600). Washington, DC: Office of Prevention, Pesticides and Toxic Substances, U.S. Environmental Protection Agency. http://www.epa.gov/opptsfrs/publications/OPPTS_Harmonized/870_Health_Effects_Test_Guidelines/Series/870-7600.pdf

U.S. EPA. 1999. Use of Values from the PHED Surrogate Table and Chemical-Specific Data, Policy Number 007. Science Advisory Council for Exposure. Dated March 11.

U.S. EPA. 2000a. Agricultural Transfer Coefficients, Policy Number 003.1. Science Advisory Council for Exposure. Revised August 7.

U.S. EPA. 2000b. The Role of Use-Related Information in Pesticide Risk Assessment and Risk Management. Office of Pesticide Programs Science Policy, dated August 21, 2000. Washington, DC: Office of Pesticide Programs, U.S. Environmental Protection Agency. http://www.epa.gov/oppbead1/use-related.pdf

U.S. EPA. 2001. Standard Values for Daily Acres Treated in Agriculture. Policy Number 009.1, Science Advisory Council for Exposure. Revised September 25.

U.S. EPA. 2002a. Reregistration Eligibility Decision for Endosulfan. Case 0014. Washington, DC: Office of Prevention, Pesticides and Toxic Substances, U.S.

Environmental Protection Agency. http://www.epa.gov/oppsrrd1/REDs/endosulfan_red.pdf

U.S. EPA. 2002b. Third Revision of "Occupational and Residential Exposure Assessment and Recommendations for the Reregistration Eligibility Decision Document for Endosulfan." DB Barcode D281052, dated February 26. Washington, DC: Office of Prevention, Pesticides and Toxic Substances, U.S. Environmental Protection Agency. http://www.epa.gov/oppsrrd1/reregistration/endosulfan/D281052.red.pdf

U.S. EPA. 2003. User's Manual: Swimmer Exposure Assessment Model (SWIMODEL) Version 3.0. Washington, DC: Office of Pesticide Programs, Antimicrobials Division, U.S. Environmental Protection Agency. http://www.epa.gov/oppad001/swimodelusersguide.pdf

U.S. EPA. 2004a. Risk Assessment Guidance for Superfund (RAGS), Volume 1: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment). July 2004. http://www.epa.gov/oswer/riskassessment/ragse/pdf/chapter3.pdf

U.S. EPA. 2004b. NRDC Consent Decree - 3rd Annual Report. EPA Actions Implementing Regulatory Determinations Required under Certain Provisions of the NRDC Consent Decree. Report dated September 24. http://www.epa.gov/oppsrrd1/nrdc2.htm

van der Merwe, D. and Riviere, J.E. 2005. Effect of vehicles and sodium lauryl sulphate on xenobiotic permeability and stratum corneum partitioning in porcine skin. Toxicology 206:325-335.

van Hemmen, J.J. 1992. Agricultural pesticide exposure data bases for risk assessment. Reviews of Environmental Contamination and Toxicology 126:1-85.

Vegetable Research and Information Center (VRIC). 2004. Division of Agriculture and Natural Resources, University of California. Website accessed for crop-specific information from September through November 2004. http://vric.ucdavis.edu.

Vercruysse, F., Drieghe, S., Steurbaut, W. and Dejonckeere. 1999. Exposure assessment of professional pesticide users during treatment of potato fields. Pesticide Science 55:467-473.

Versar. 1992. PHED: The Pesticide Handlers Exposure Database Reference Manual. Prepared for the PHED Task Force: Health and Welfare Canada, U. S. Environmental Protection Agency, National Agricultural Chemicals Association. Springfield, VA: Versar, Inc.

Ware G.W., Morgan, D.P., Estesen, B.J., Cahill, W.P. and Whitacre, D.M. 1973. Establishment of reentry intervals for organophosphate-treated cotton fields based on human data: I. Ethyl- and methyl parathion. Archives of Environmental Contamination and Toxicology 1:48-59.

Ware G.W., Morgan, D.P., Estesen, B.J. and Cahill, W.P. 1974. Establishment of reentry intervals for organophosphate-treated cotton fields based on human data: II. Azodrin, ethyl and methyl parathion. Archives of Environmental Contamination and Toxicology 2:117-129.

Ware G.W., Morgan D.P., Estesen B.J. and Cahill, W.P. 1975. Establishment of reentry intervals for organophosphate-treated cotton fields based on human data: III. 12 to 72 hours post-treatment exposure to monocrotophos, ethyl- and methyl parathion. Archives of Environmental Contamination and Toxicology 3:289-306.

Weston, D.P., You, J. and Lydy, M.J. 2004. Distribution and toxicity of sediment-associated pesticides in agriculture-dominated water bodies of California's Central Valley. Environmental Science and Technology 38:2752-2759.

Wester, R.C. and Maibach, H.I. 2000. Understanding percutaneous absorption for occupational health and safety. International Journal of Occupational and Environmental Health 6:86-92.

Whitmyre, G.K., Ross, J.H., Lunchick, C., Volger, B. and Singer, S. 2004. Biphasic dissipation kinetics for dislodgeable foliar residues in estimating postapplication occupational exposures to endosulfan. Archives of Environmental Contamination and Toxicology 46:17-23.

Wiley, J.A., Robinson, J.P., Piazza, T., Garrett, K., Cirksena, K., Cheng, Y.T. and Martin, G. 1991. Activity Patterns of California Residents. Contract No. A6-177-33. Final Report. Sacramento, CA: Air Resources Board, Research Division, California Environmental Protection Agency. http://www.arb.ca.gov/research/abstracts/a6-177-33.htm

Williams, A.C. and Barry, B.W. 2004. Penetration enhancers. Advanced Drug Delivery Reviews 56:603-618.

Willis, G.H. and McDowell, L.L. 1987. Pesticide persistence on foliage. Reviews in Environmental Contamination and Toxicology 100:22-73.

Wilson, A.G.L., Desmarchelier, J.M. and Malafant, K. 1983. Persistence on cotton foliage of insecticide residues toxic to Heliothis larvae. Pesticide Science 14:23-633.

Wolfe, H.R., Armstrong, J.F., Staiff, D.C., Comer, S.W. and Durham, W.F. 1975. Exposure of apple thinners to parathion residues. Archives of Environmental and Contamination Toxicology 3:257-267.

Worker Health and Safety (WHS). 2007. Summary of Results from the California Pesticide Illness Surveillance Program, 2005. Report No. HS-1869. Sacramento, CA: Worker Health and Safety Branch, Department of Pesticide Regulation, California Environmental Protection Agency. http://www.cdpr.ca.gov/docs/whs/pdf/hs1869.pdf

Zendzian, R.P. and Dellarco, M. 2003. Validating in vitro dermal absorption studies: An introductory case study. Chapter 18 in: Salem, H. and Katz, S.A., editors. Alternative Toxicological Methods. CRC Press, Boca Raton.

Zweig, G., Gao, R.-Y., Witt, J.M., Popendorf, W. and Bogen. K. 1984. Dermal exposure to carbaryl by strawberry harvesters. Journal of Agricultural and Food Chemistry 32:1232-1236.

Zweig, G., Leffingwell, J.T. and Popendorf, W. 1985. The relationship between dermal pesticide exposure by fruit harvesters and dislodgeable foliar residues. Journal of Environmental Science and Health B20:27-59.

APPENDICES

Appendix 1 summarizes information used in determining representative reentry scenarios and in estimating reentry worker exposure for crops for which endosulfan use is registered in California.

Appendix 2 summarizes dislodgeable foliar residue (DFR) values used in reentry exposure estimates.

Appendices 3 – 12 provide detailed information on values used in handler exposure estimates. As described in the Exposure Assessment section, the Pesticide Handlers Exposure Database (PHED) combines exposure data from multiple field monitoring studies of different active ingredients (AIs). The user selects a subset of the data having the same or a similar application method and formulation type as the target scenario. Once the PHED subsets were generated, inputs for exposure calculations were entered, according to DPR policy. Exposures were requested in mg per pound of AI handled, because the total work time spent within each handling task is not as well defined. For dermal exposure, both actual and estimated head patches were included. For inhalation exposure, the DPR default inhalation rate for handlers of 16.7 L/min was used. Protective clothing and equipment were chosen based on requirements on product labels and in state and federal laws.

Due to an error in PHED (U.S. EPA, 1998a), values for foot exposures are incorrectly reported, and often omitted entirely. Dermal totals were corrected by addition of the best estimate of feet exposure, calculated by multiplying the value for lower legs by 0.52 (ratio of feet/lower leg surface area; U.S. EPA, 1997).

Appendices 13 and 14 show calculations of exposure for workers dipping nursery stock in endosulfan solutions, based on models made available by U.S. EPA.

Appendix 15 summarizes changes to exposure estimates if mitigation measures proposed by U.S. EPA (2002a) are implemented. This information is provided to assist risk managers in determining whether the measures proposed in U.S. EPA (2002a) would be sufficient to mitigate any exposure concerns in California.

APPENDIX 1: AGRICULTURAL REENTRY SCENARIOS TABLE

This table was prepared by reviewing endosulfan product labels. Maximum application rates and minimum preharvest intervals (PHI) were chosen when they differed between labels; however, application rates and PHI were generally the same on all labels. Under California law, the restricted entry interval for all crops is 2 days.

Rows are sorted by site category (FC = Field Crops; FN = Fruits and Nuts; V = Vegetables; OT = Ornamentals, Herbs, Trees, Nursery/Greenhouse), then by use sites.

In preparing the table, reentry activities were listed for each site, then assigned to tiers based on anticipated exposure. Tier I: Most of the body is in contact with residues. Tier II: Some of the body is in contact with residues (e.g., hands, arms and face; or hands, forearms, feet, and lower legs). Tier III: Very little of the body is in contact with residues (e.g., hands only; or hands and feet only).

Within Tier I and Tier II, suggested representative activities are shown in bold. These are activities that generally should be addressed specifically in an exposure assessment. Tier III activities are considered to be covered by Tier I and Tier II activities. For crops where more than one activity is shown in bold, each activity should be considered in light of pesticide-specific information (i.e., one activity doesn't consistently represent the others). For some pesticides, activities not shown in bold should also be considered.

Site Cat [a]	Use Site	Rate [b] (lb AI/A)	PHI [c] (days)	Tier I Activities (High)	Tier II Activities (Medium)	Tier III Activities (Low)
FC	Alfalfa grown for seed only (SLN 24c)	1	21	None	None	Irrigating [d], Scouting, Harvesting
FC	Barley, Oats, Rye, Wheat	0.75	None	None	None	Irrigating [d], Scouting, Harvesting, Swathing
FC	Clover grown for seed only (SLN 24c)	0.5	NA	None	None	Irrigating [d], Scouting, Harvesting, Weeding
FC	Corn, Sweet	1.5	1	**Scouting, Hand Harvesting**	None	Irrigating [d], Weeding, Mech. Harvesting
FC	Cotton	1.5	NA	Scouting	Irrigating [d], Hand Weeding/Roguing, Harvesting	None
FC	Safflower, Sunflower	1	0	None	Irrigating, **Scouting**	Weeding, Mech. Harvesting
FC	Tobacco	1	5	**Hand Harvesting**	**Scouting**	Irrigating [d], Harvesting, Pruning, Stripping, Thinning, Topping, Weeding, Reset

Site Cat [a]	**Use Site**	**Rate** [b] **(lb AI/A)**	**PHI** [c] **(days)**	**Tier I Activities (High)**	**Tier II Activities (Medium)**	**Tier III Activities (Low)**
FN	Almond, Filbert, Macadamia Nut, Pecan, Walnut	2.5	14	Harvesting (Hand) [g]	**Harvesting** (Mechanical Shake and Sweep [f])	Weeding (Mechanical), Irrigating [d], Scouting, Transplant/Propagate [e], Pruning (Dormant)
FN	Apple	2.5	21	**Thinning**	**Harvesting** (Hand), Pruning (Nondormant), Propping	Scouting, Irrigating [d], Weeding, Pruning And Tying (Dormant), Transplant/Propagate [e]
FN	Apricots, Nectarines, Peaches	2.5	21	**Thinning**	**Harvesting** (Hand), Pruning (Nondormant), Propping	Scouting, Irrigating [d], Weeding (Mechanical), Pruning (Dormant), Transplant/Propagate [e]
FN	Cherries	2.5	21	**Thinning**	**Harvesting** (Hand), Pruning (Nondormant)	Irrigating [d], Scouting, Weeding, Harvesting (Mechanical), Fertilizing, Transplant/Propagate [e], Pruning (Dormant)
FN	Citrus (Non-bearing trees and nursery stock)	2.5	NA	None (no fruit)	None (no fruit, minimal foliage)	Irrigating [d], Weeding, Scouting, Transplant/Propagate [e], Pruning first year
FN	Grapes	1.5	7	**Leaf Pulling/Cane Turning,** Cane Cutting, Thinning	**Harvest** (Hand), Scouting, Pruning (Nondormant)	Weeding (Hand), Girdling, Pruning, Training/Tying/ Trellising, Transplant/Propagate [e]
FN	Pears	2.5	7	**Harvest** (Hand), Thinning	**Pruning** (Nondormant)	Scouting, Irrigating [d], Weeding (Hand, Mechanical), Propping, Pruning And Tying (Dormant), Transplant/Propagate [e]
FN	Pineapple (Fresh Market)	2	7	**Harvest** (Hand)	**Scouting**	Harvest (Mechanical), Irrigating [d], Weeding (Hand), Transplant/Propagate [e]
FN	Plums, Prunes	2.5	7	**Thinning**	**Harvest** (Hand), Pruning (Nondormant)	Irrigating [d], Scouting, Pruning (Dormant), Weeding (Mechanical), Transplant/Propagate [e]
FN	Strawberry	2	4	None	**Harvest (Hand)**, Pruning/Pinching	Scouting, Irrigating [d], Weeding/Runner Cut, Mulching, Training, Transplant/Propagate [e]
OT	Cherry, Peach, Plum (Nursery Stock Dip)	2 lbs per 40 gallons	NA	None	None	Packing of Treated Plants, Planting by Hand
OT	Ornamentals, Greenhouse and Out-Of-Doors	1 lb per 100 gal drench	NA	None	**Hand Harvesting Cut Flowers**	Scouting, Irrigating [d], Pruning, Thinning, Weeding, Transplanting

Site Cat [a]	Use Site	Rate [b] (lb AI/A)	PHI [c] (days)	Tier I Activities (High)	Tier II Activities (Medium)	Tier III Activities (Low)
OT	Ornamental Trees and Shrubs	1 lb per 100 gal drench	NA	None	None	Scouting, Harvesting, Chopping Brush, Irrigating [d], Pruning, Thinning, Weeding, Transplanting
V	Beans, Succulent and Dry	1	3	Tying, Staking, **Harvesting (Hand)**	Irrigating [d], **Scouting**	Weeding, Transplanting[e], Harvesting (Mechanical)
V	Broccoli, Cabbage,	1	7	**Harvesting (Hand)**	Irrigating [d], **Scouting**	Weeding, Thinning, Transplanting [e], Harvesting (Mechanical)
V	Brussels Sprouts, Cauliflower	1	14	Irrigating, Topping, **Harvesting (Hand)**	**Scouting**	Weeding, Thinning, Transplanting [e], Harvesting (Mechanical)
V	Carrots	1	7	None	Harvesting (Hand)	Scouting, Irrigating, Weeding, Harvesting (Mechanical)
V	Celery	1	4	**Harvesting (Hand)**	Irrigating [d], **Scouting**	Weeding, Transplanting[e]
V	Collards	0.75	21	**Harvesting (Hand)**	Irrigating [d], **Scouting**	Weeding, Thinning, Transplanting [e]
V	Crucifers for seed only (Broccoli, Cabbage, Collards, Chinese Cabbage, Kale, Mustard, Kohlrabi, Rape, Rutabaga, Turnips)	2	NA	None	**Harvest**, Pruning, Training, Weeding (Hand)	Scouting, Irrigating, Weeding, Transplanting
V	Cucumbers, Melons, Pumpkins, Summer and Winter Squash	1	2	Tying, Staking, **Harvesting (Hand)**	Irrigating [d], **Scouting**	Weeding, Thinning, Transplanting [e], Harvesting (Mechanical)
V	Eggplant	1	1	Pruning (Hand) [g], **Harvesting (Hand)**	Irrigating [d], **Scouting**	Weeding, Transplanting[e]
V	Kale	0.75	21	None	Irrigating [d], Scouting, **Harvesting (Hand)**	Weeding, Thinning, Transplanting [e]
V	Lettuce	1	14	Head Breaking (For Head), **Harvesting (Hand)**	Irrigating [d], **Scouting**	Thinning, Weeding, Transplanting [e]

Site Cat [a]	Use Site	Rate [b] (lb AI/A)	PHI [c] (days)	Tier I Activities (High)	Tier II Activities (Medium)	Tier III Activities (Low)
V	Mustard Greens	0.75	21	**Harvesting (Hand)**	Irrigating [d], **Scouting**	Thinning, Weeding, Transplanting [e], Harvesting (Mechanical)
V	Peas, Succulent	1	0	**Harvesting (Hand)**	Irrigating [d], **Scouting**	Weeding, Harvesting (Mechanical)
V	Peppers	1 (or 0.5)	4 (or 1)	Thinning, **Harvesting (Hand)**	Irrigating [d], **Scouting**	Weeding, Transplanting[e]
V	Potato (White, Irish, Red, Russet)	1	1	None	Irrigating [d], **Scouting,** Harvesting (Hand) [e]	Weeding, Transplanting[e], Harvesting (Mechanical)
V	Spinach	0.75	21	None	Irrigating [d]**,** Scouting, **Harvesting (Hand)**	Thinning, Weeding, Transplanting [e], Harvesting (Mechanical)
V	Sugar Beets	1	30	Harvesting (Hand) [g]	Irrigating [d], **Scouting**	Weeding, Thinning, Harvesting (Mechanical)
V	Sweet Potato	1	1	None	Irrigating [d], **Scouting,** Harvesting (Hand) [g]	Weeding, Transplanting[e], Harvesting (Mechanical)
V	Tomato (Fresh Market)	1	2	Tying, Training, Staking, Pruning (Hand) [d], **Harvesting (Hand)**	Irrigating [d], **Scouting**	Weeding, Thinning, Transplanting [e]
V	Tomato (Processing/ Canning)	1	2	Tying, Training, Staking	Irrigating [d], **Scouting,** Pruning (Hand) [a]	Weeding, Transplanting[e], Harvesting (Mechanical)

[a] Site categories: FC = Field Crops; FN = Fruits and Nuts; M = Miscellaneous; OT = Ornamentals, Herbs, Trees, Nursery/Greenhouse; V = Vegetables.
[b] Rate = Maximum application rate listed for crop in California on any product label.
[c] PHI = Minimum preharvest interval listed for crop in California on any product label.
[d] Irrigator exposure is dependent upon the method of irrigation used for the crop, where drip irrigation is Tier III (low), flood or furrow irrigation of crops less than 18 inches high is Tier III (low), flood or furrow irrigation of crops 18 inches or taller is Tier II (moderate), sprinkler irrigation of crops less than 18 inches high is Tier II (moderate), and sprinkler irrigation of crops 18 inches or taller is Tier I (high).
[e] Transplant/propagate activity has little potential for exposure in the field, but may present a potential for exposure during the propagation stage in the nursery or greenhouse setting. Refer to greenhouse/nursery scenarios.
[f] Mechanical harvesting by shaking and sweeping to drop and collect fruits/nuts, respectively, may generate dust and debris (falling leaves, branches, produce) sufficient to expose harvester to pesticide residues by dermal contact with or inhalation of debris/dust. However, no residue transfer data are available for this scenario at present.
[g] This activity isn't practiced commercially in California at present.

APPENDIX 2: DISLODGEABLE FOLIAR RESIDUES FOR ENDOSULFAN

Table 2-1. Measured DFR for Endosulfan Applied to Melons, Peaches, or Grapes

Day	Measured DFR (µg/cm²) [a]					
	Melons		Peaches		Grapes	
	EC [b]	WP [b]	EC	WP	EC	WP
0	1.23	1.00	0.46	1.02	0.71	1.32
1	0.54	1.14	0.16	0.55	0.31	1.36
3	0.15	0.53	0.09	0.43	0.11	0.51
5	0.09	0.32	0.07	0.30	0.09	0.74
7	0.06	0.18	0.04	0.22	0.03	0.28
10	0.05	0.12	0.03	0.16	0.02	0.20
14	0.05	0.07	0.03	0.11	0.04	0.24
17	0.03	0.04	0.03	0.10	0.05	0.30
21	0.02	0.02	0.05	0.09	0.02	0.20
24	0.02	0.04	0.02	0.07	0.04	0.19
28	0.02	0.03	0.01	0.04	< LOQ [c]	0.13

[a] Dislodgeable foliar residue (DFR) data from Table 1 in Whitmyre *et al.* (2004). Applications and sample collection in July through September 1995 in Fresno County (Singer, 1997). Results include combined residues from α-endosulfan, β-endosulfan and endosulfan sulfate. Applications: melons, 2 at 1 lb AI/acre; grapes, 2 at 1.5 lb AI/acre; peaches, one at 3 lbs AI/acre. Laboratory fortifications had overall recovery means ± SD of 80 ± 5%, 85 ± 4%, and 91 ± 3% for α-endosulfan, β-endosulfan, and endosulfan sulfate, respectively (Singer, 1997). No field fortifications were reported.

[b] EC: emulsifiable concentrate. WP: wettable powder.

[c] Limit of Quantification (LOQ): 0.01 µg/cm².

Table 2-2. Predicted DFR for Endosulfan Applied to Melons, Peaches, or Grapes

Day	Predicted DFR (µg/cm²) [a]					
	Melons		Peaches		Grapes	
	EC [b]	WP [b]	EC	WP	EC	WP
0	0.40	1.4	0.11	0.48	0.17	1.1
1	0.31	1.1	0.10	0.44	0.15	0.95
2	0.25	0.78	0.095	0.41	0.14	0.83
3	0.20	0.58	0.089	0.37	0.13	0.73
4	0.16	0.44	0.083	0.34	0.12	0.64
5	0.13	0.34	0.077	0.31	0.11	0.57
6	0.11	0.27	0.072	0.29	0.10	0.51
7	0.092	0.21	0.067	0.26	0.091	0.45
10	0.056	0.11	0.054	0.20	0.070	0.34
14	0.034	0.058	0.041	0.14	0.048	0.24
17	0.026	0.041	0.033	0.11	0.036	0.21
21	0.022	0.031	0.024	0.077	0.024	0.18
24	0.021	0.029	0.019	0.059	0.018	0.17

[a] Dislodgeable foliar residue (DFR) data from Whitmyre *et al.* (2004). Regression equations yielding predicted DFR shown in Table 8. Unbiased predicted values obtained by backtransformation using SAS Proc REG (SAS, 2003).

[b] EC: emulsifiable concentrate. WP: wettable powder.

Table 2-3. Measured and Predicted DFR for Endosulfan Applied to Tomato, Celery, or Bok Choy

Day	Measured DFR (μg/cm^2) [a]					
	Tomato		Celery		Bok Choy	
	Measured	Predicted [b]	Measured	Predicted [b]	Measured	Predicted [b]
0	0.2408	0.135	0.1123	0.151	0.195	0.253
1	0.0743	0.0770	0.0322	0.123	0.122	0.166
1.5	ND [c]	ND	0.1008	ND	ND	ND
2	ND	0.0456	0.227	0.0996	0.124	0.108
3	0.0307	0.0282	ND	0.0800	0.095	0.0701
4	ND	0.0183	ND	0.0638	ND	0.0454
5	0.0117	0.0124	ND	0.0506	ND	0.0294
6	ND	0.0087	ND	0.0398	ND	0.0189
7	ND	0.0065	0.0193	0.0311	0.006	0.0122
10	ND	0.0034	ND	0.0142	ND	0.0032
13	0.0027	0.0027	0.0056	0.0061	0.0016	0.0008

[a] Dislodgeable foliar residue (DFR) data from Table 1 in Maddy *et al.* (1985). All applications were 1.0 lb AI/acre, emulsifiable concentrate formulation. Results include combined residues from α-endosulfan, β-endosulfan and endosulfan sulfate.
[b] Regression equations yielding predicted DFR shown in Table 8. Unbiased predicted values obtained by backtransformation using SAS Proc REG (SAS, 2003).
[c] ND = Not determined.

APPENDIX 3: SUBSET FROM PHED FOR MIXER/LOADERS OF LIQUID FORMULATIONS

Table 3-1. Description of Pesticide Handlers Exposure Database (PHED) subsets [a]

Parameter	Specifications used to generate subsets [a]	Actual characteristics of resulting subsets
Data Quality Grades [b]	A,B	A
Liquid Type	Emulsifiable concentrate, aqueous suspension, microencapsulated, solution, or undiluted liquid	All emulsifiable concentrate
Mixing Procedure	Closed, mechanical pump or gravity feed	Closed

[a] Subsets of Mixer/Loader data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.
[b] Data quality for Airborne, Dermal Uncovered, Dermal Covered and Hand are all Grade A. Data quality grades are defined in the text and in Versar (1992).

Figure 3-1. Summary of results from the PHED dermal subset [a]

SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES
SCENARIO: Long pants, long sleeves, gloves

PATCH LOCATION	MICROGRAMS PER LB AI MIXED Mean	Coef of Var	Geo. Mean	Obs.
HEAD (ALL)	1.6959	121.3279	.9508	22
NECK.FRONT	1.5225	278.5222	.2418	22
NECK.BACK	.456	280.8991	.0729	22
UPPER ARMS	1.3441	96.6967	.7988	21
CHEST	1.8416	93.4405	1.0577	16
BACK	1.8416	93.4405	1.0577	16
FOREARMS	.5474	98.5203	.3206	21
THIGHS	2.3398	81.9301	1.5773	16
LOWER LEGS	1.292	85.7276	.8778	21

Subset Name:
S6DERMAL.MLOD

[a] Subset criteria included actual and estimated head patches. Of the 22 head observations, all were actual.

Table 3-2. PHED data from dermal, hand, and inhalation subsets [a]

Exposure Category	Exposure (µg/lb AI handled)	Replicates in subset	Short-term Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand) [c]	13.6	21 [d]	4	1
Hand (with gloves)	5.72	31	4	1
Inhalation	0.128	27	4	1

[a] Results from subsets of Mixer/Loader data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.
[b] Multipliers are explained in the text and in Powell (2002).
[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (US EPA, 1997).
[d] Median number of replicates was used in determining subset multipliers.

Table 3-3. Values Used in Exposure Calculations [a]

	Short-Term Exposure	Long-Term Exposure
Total Dermal (all PPE) [b]	4(3.52 +5.72) = 37.0 µg/lb AI handled	1(3.52 + 5.72) = 9.52 µg/lb AI handled
Inhalation	4(0.128) = 0.512 µg/lb AI handled	1(0.128) = 0.128 µg/lb AI handled

[a] Values from Table 3-2. Results rounded to three significant figures.
[b] Estimates adjusted for personal protective equipment (PPE): coveralls assumed to provide 90% protection (Thongsinthusak *et al*, 1991) to all but head, hands, and feet; chemical-resistant apron assumed to provide 95% protection (Thongsinthusak *et al*, 1991) to chest and front half of thighs.

APPENDIX 4: SUBSET FROM PHED FOR MIXER/LOADERS, WETTABLE POWDERS

Table 4-1. Description of Pesticide Handlers Exposure Database (PHED) subsets [a]

Parameter	Specifications used to generate subsets [a]	Actual characteristics of resulting subsets
Data Quality Grades [b]	A,B	A,B
Solid Type	Wettable powder	Wettable powder
Mixing Procedure	Open	Open

[a] Subsets of Mixer/Loader data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.
[b] Data quality for Dermal Uncovered, Dermal Covered and Hand are all Grade A or B; Airborne data are all Grade A. Data quality grades are defined in the text and in Versar (1992).

Figure 4-1. Summary of results from the PHED dermal subset [a]

SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES
SCENARIO: Long pants, long sleeves, gloves

PATCH LOCATION	MICROGRAMS PER LB AI MIXED Mean	Coef of Var	Geo. Mean	Obs.
HEAD (ALL)	12.1008	159.063	3.243	24
NECK.FRONT	49.7781	241.7376	1.6288	24
NECK.BACK	35.299	250.8502	.9205	24
UPPER ARMS	181.099	412.7976	15.4083	30
CHEST	155.2533	458.3228	9.6478	36
BACK	165.361	437.2647	9.8479	36
FOREARMS	12.2599	180.986	4.6336	28
THIGHS	5.7027	140.9473	2.8042	28
LOWER LEGS	4.046	120.7341	1.9477	28

Subset Name:
S1DERMAL.MLOD

[a] Subset criteria included actual and estimated head patches. Of the 24 head observations, all were actual.

Table 4-2. PHED data from dermal, hand, and inhalation subsets for Scenario 1 [a]

Exposure Category	Exposure (µg/lb AI handled)	Replicates in subset	Short-Term Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand) [c]	623	28 [d]	4	1
Hand (with gloves)	23.7	20	4	1
Inhalation	49.4	17	5	1

[a] Results from subsets of Mixer/Loader data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.
[b] Multipliers are explained in the text and in Powell (2002).
[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (U.S. EPA, 1997).
[d] Median number of replicates was used in determining subset multipliers.

Table 4-3. Values Used in Scenario 1 Exposure Calculations [a]

	Short-Term Exposure	Long-Term Exposure
Total Dermal (all PPE) [b]	4(74.3) + 4(23.7) = 392 µg/lb AI handled	1(74.3) + 1(23.7) = 98.0 µg/lb AI handled
Inhalation [c]	5(4.94) = 24.7 µg/lb AI handled	1(4.94) = 4.94 µg/lb AI handled

[a] Values from Table 4-2. Results rounded to three significant figures.
[b] Estimates adjusted for personal protective equipment (PPE): coveralls assumed to provide 90% protection (Thongsinthusak *et al*, 1991) to all but head, hands, and feet; chemical-resistant apron assumed to provide 95% protection (Thongsinthusak *et al*, 1991) to chest and front half of thighs.
[c] 90% protection factor applied to inhalation exposure for use of respirator (NIOSH, 1987).

APPENDIX 5: SUBSET FROM PHED FOR MIXER/LOADERS OF WETTABLE POWDER FORMULATIONS IN WATER SOLUBLE PACKAGING

Table 5-1. Description of Pesticide Handlers Exposure Database (PHED) subsets [a]

Parameter	Specifications used to generate subsets [a]	Actual characteristics of resulting subsets
Data Quality Grades [b]	A,B	A,B
Solid Type	Wettable powder	Wettable Powder
Package Type	Water Soluble Bag	Water Soluble Bag

[a] Subsets of Mixer/Loader data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.
[b] Data quality for Dermal Uncovered, Dermal Covered and Hand are all Grade A or B; Airborne data are all Grade A. Data quality grades are defined in the text and in Versar (1992).

Figure 5-1. Summary of results from the PHED dermal subset [a]

SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES
SCENARIO: Long pants, long sleeves, gloves

PATCH LOCATION	MICROGRAMS PER LB AI MIXED Mean	Coef of Var	Geo. Mean	Obs.
HEAD (ALL)	3.51	165.0541	1.1942	15
NECK.FRONT	.423	155.9811	.1734	15
NECK.BACK	.2933	167.61	.0978	15
UPPER ARMS	2.619	17.2127	2.5837	6
CHEST	1.8046	83.2317	1.1207	12
BACK	1.8046	83.2317	1.1207	12
FOREARMS	1.089	17.2176	1.0743	6
THIGHS	4.9023	204.1674	1.6636	12
LOWER LEGS	1.19	86.1261	.7092	12

Subset Name:
S3DERMAL.MLOD

[a] Subset criteria included actual and estimated head patches. Of the 15 head observations, all were actual.

Table 5-2. PHED data from dermal, hand, and inhalation subsets [a]

Exposure Category	Exposure (µg/lb AI handled)	Replicates in subset	Short-Term Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand) [c]	18.3	12 [d]	5	2
Hand (with gloves)	0.056	6	9	2
Inhalation	0.277	12	5	2

[a] Results from subsets of Mixer/Loader data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.
[b] Multipliers are explained in the text and in Powell (2002).
[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (U.S. EPA, 1997).
[d] Median number of replicates was used in determining subset multipliers.

Table 5-3. Values Used in Exposure Calculations [a]

	Short-Term Exposure	Long-Term Exposure
Total Dermal (all PPE) [b]	5(5.57) + 9(0.056) = 28.4 µg/lb AI handled	2(5.57) + 2(0.056) = 11.3 µg/lb AI handled
Inhalation	5(0.277) = 1.38 µg/lb AI handled	2(0.277) = 0.554 µg/lb AI handled

[a] Values from Table 5-2. Results rounded to three significant figures.
[b] Estimates adjusted for personal protective equipment (PPE): coveralls assumed to provide 90% protection (Thongsinthusak *et al*, 1991) to all but head, hands, and feet; chemical-resistant apron assumed to provide 95% protection (Thongsinthusak *et al*, 1991) to chest and front half of thighs.

APPENDIX 6: SUBSET FROM PHED FOR AERIAL APPLICATORS

Table 6-1. Description of Pesticide Handlers Exposure Database (PHED) subsets [a]

Parameter	Specifications used to generate subsets [a]	Characteristics of resulting subsets
Data Quality Grades [b]	A,B,C	A,B,C
Liquid Type	Not specified	All emulsifiable concentrate
Solid Type	Exclude granular	none
Application Method	Fixed- or rotary-wing	All fixed-wing
Cab Type	Open Cab or Closed Cab with Open Window	Open Cab or Closed Cab with Open Window

[a] Subsets of Applicator data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.
[b] Data quality for Dermal Uncovered, Dermal Covered, and Hand were Grade A or C; Airborne data were Grade B or C. Data quality grades are defined in the text and in Versar (1992).

Figure 6-1. Summary of results from the PHED dermal subset [a]

SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES
SCENARIO: Long pants, long sleeves, gloves

PATCH LOCATION	MICROGRAMS PER LB AI SPRAYED Mean	Coef of Var	Geo. Mean	Obs.
HEAD (ALL)	4.212	118.2574	1.2438	10
NECK.FRONT	.414	143.6715	.1169	10
NECK.BACK	.3124	139.1485	.0741	10
UPPER ARMS	8.5554	109.6232	5.7532	10
CHEST	6.3065	158.1987	2.1395	17
BACK	8.7497	141.5614	3.131	17
FOREARMS	2.7901	131.7516	1.1744	17
THIGHS	9.55	157.4126	3.4718	13
LOWER LEGS	7.4494	138.0769	3.3312	10

Subset Name:
S17DERMAL.APPL

[a] Subset criteria included actual and estimated head patches. Of the 10 head observations, 7 were actual and 3 were estimated from nearby patches (Versar, 1992).

Table 6-2. PHED data from dermal, hand, and inhalation subsets [a]

Exposure Category	Exposure (µg/lb AI handled)	Replicates in subset	Short-Term Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand) [c]	52.2	10 [d]	6	2
Hand (with gloves)	9.63	9	6	2
Inhalation	0.573	14	5	2

[a] Results from subsets of Applicator data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.
[b] Multipliers are explained in the text and in Powell (2002).
[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (U.S. EPA, 1997).
[d] Median number of replicates was used in determining subset multipliers.

Table 6-3. Values Used in Exposure Calculations [a]

	Short-Term Exposure	Long-Term Exposure
Total Dermal (all PPE) [b]	6(12.5) + 6(9.63) = 133 µg/lb AI handled	2(12.5) + 2(9.63) = 44.3 µg/lb AI handled
Inhalation [c]	5(0.0573) = 0.286 µg/lb AI handled	2(0.0573) = 0.115 µg/lb AI handled

[a] Values from Table 6-2. Results rounded to three significant figures.
[b] Estimates adjusted for personal protective equipment (PPE): coveralls assumed to provide 90% protection (Thongsinthusak *et al*, 1991) to all but head, hands, and feet.
[c] 90% protection factor applied to inhalation exposure for use of respirator (NIOSH, 1987).

APPENDIX 7: SUBSET FROM PHED FOR FLAGGERS

Table 7-1. Description of Pesticide Handlers Exposure Database (PHED) subsets [a]

Parameter	Specifications used to generate subsets [a]	Characteristics of resulting subsets
Data Quality Grades [b]	A,B	A,B
Liquid Type or Solid Type	Not specified	Emulsifiable concentrate or dry flowable
Application Method	Fixed- or rotary-wing	All rotary-wing

[a] Subsets of Flagger data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.
[b] Data quality for Dermal Uncovered and Dermal Covered are all Grade A; Airborne and Hand data are all Grade A or B. Data quality grades are defined in the text and in Versar (1992).

Figure 7-1. Summary of results from the PHED dermal subset [a]

SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES
SCENARIO: Long pants, long sleeves, gloves

PATCH LOCATION	MICROGRAMS PER LB AI SPRAYED Mean	Coef of Var	Geo. Mean	Obs.
HEAD (ALL)	11.3028	127.5702	5.6188	18
NECK.FRONT	.9533	134.3334	.5146	18
NECK.BACK	1.4111	215.8529	.4931	18
UPPER ARMS	3.9285	195.1025	.8284	28
CHEST	5.1065	188.8378	1.0384	26
BACK	5.1065	188.8378	1.0384	26
FOREARMS	1.802	179.5283	.3837	28
THIGHS	4.0404	308.6996	.9165	26
LOWER LEGS	2.448	305.6618	.612	28

Subset Name:
S7DERMAL.FLAG

[a] Subset criteria included actual and estimated head patches. Of the 18 head observations, all were actual.

Table 7-2. PHED data from dermal, hand, and inhalation subsets [a]

Exposure Category	Exposure (µg/lb AI handled)	Replicates in subset	Short-Term Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand)	37.4	26 [d]	4	1
Hand (no gloves)	5.97	30	4	1
Inhalation	0.200	28	4	1

[a] Results from subsets of Flagger data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.
[b] Multipliers are explained in the text and in Powell (2002).
[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (U.S. EPA, 1997).
[d] Median number of replicates was used in determining subset multipliers.

Table 7-3. Values Used in Exposure Calculations [a]

	Short-Term Exposure	Long-Term Exposure
Total Dermal (with PPE) [b]	4(15.1 + 0.597) = 62.8 µg/lb AI handled	1(15.1 + 0.597) = 16.0 µg/lb AI handled
Inhalation [c]	4(0.020) = 0.080 µg/lb AI handled	1(0.020) = 0.020 µg/lb AI handled

[a] Values from Table 7-2. Results rounded to three significant figures.
[b] Estimates adjusted for personal protective equipment (PPE): gloves assumed to provide 90% protection (Aprea *et al*, 1994); exposure of gloved hands is calculated as one tenth exposure of bare hands. Coveralls assumed to provide 90% protection (Thongsinthusak *et al*, 1991) to all but head, hands, and feet.
[c] 90% protection factor applied to inhalation exposure for use of respirator (NIOSH, 1987).

APPENDIX 8: SUBSET FROM PHED FOR GROUNDBOOM APPLICATORS

Table 8-1. Description of Pesticide Handlers Exposure Database (PHED) subsets [a]

Parameter	Specifications used to generate subsets [a]	Actual characteristics of resulting subsets
Data Quality Grades [b]	A,B	A,B,C
Liquid Type or Solid Type	Not specified	Emulsifiable concentrate or wettable powder
Application Method	Groundboom, Truck or Tractor	Groundboom, Tractor
Cab Type	Open Cab or Closed Cab with Open Window	Open Cab or Closed Cab with Open Window

[a] Subsets of Applicator data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.
[b] Data quality grades for Airborne, Dermal Uncovered, Dermal Covered and Hand are all Grade A or B, with the exception of one dermal replicate that has Dermal Uncovered Grade C (Dermal Covered for that replicate is Grade B). Data quality grades are defined in the text and in Versar (1992).

Figure 8-1. Summary of results from the PHED dermal subset [a]

SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES

SCENARIO: Long pants, long sleeves, no gloves

PATCH LOCATION	MICROGRAMS PER LB AI SPRAYED Mean	Coef of Var	Geo. Mean	Obs.
HEAD (ALL)	2.7891	136.1192	1.0464	33
NECK.FRONT	1.5763	167.9503	.3296	23
NECK.BACK	1.0063	173.5765	.2335	29
UPPER ARMS	1.6914	88.749	1.1637	32
CHEST	1.7581	98.5154	1.1329	42
BACK	3.0175	233.2361	1.3959	42
FOREARMS	2.7301	419.1055	.564	32
THIGHS	3.1255	185.5703	1.1806	33
LOWER LEGS	2.1148	172.3425	.7466	35

Subset Name: S11DERMAL.APPL

[a] Subset criteria included actual and estimated head patches. Of the 33 head observations, all were actual.

Table 8-2. PHED data from dermal, hand, and inhalation subsets [a]

Exposure Category	Exposure (µg/lb AI handled)	Replicates in subset	Short-Term Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand) [c]	20.9	33 [d]	4	1
Hand (no gloves)	45.6	29	4	1
Inhalation	1.18	22	4	1

[a] Results from subsets of Applicator data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.
[b] Multipliers are explained in the text and in Powell (2002).
[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (U.S. EPA, 1997).
[d] Median number of replicates was used in determining subset multipliers.

Table 8-3. Values Used in Exposure Calculations [a]

	Short-Term Exposure	Long-Term Exposure
Total Dermal (all PPE) [b]	4(5.58 + 4.56) = 40.6 µg/lb AI handled	1(5.58 + 4.56) = 6.04 µg/lb AI handled
Inhalation [c]	4(0.118) = 0.472 µg/lb AI handled	1(0.118) = 0.118 µg/lb AI handled

[a] Values from Table 8-2. Results rounded to three significant figures.
[b] Estimates adjusted for personal protective equipment (PPE): gloves assumed to provide 90% protection (Aprea *et al*, 1994); coveralls assumed to provide 90% protection (Thongsinthusak *et al*, 1991) to all but head, hands, and feet.
[c] 90% protection factor applied to inhalation exposure for use of respirator (NIOSH, 1987).

APPENDIX 9: SUBSET FROM PHED FOR MIXER/LOADER/APPLICATORS USING BACKPACK SPRAYERS

Table 9-1. Description of Pesticide Handlers Exposure Database (PHED) subsets [a]

Parameter	Specifications used to generate subsets [a]	Actual characteristics of resulting subsets
Data Quality Grades [b]	A,B,C	A,B,C
Liquid Type	Not specified	Solution, Microencapsulated
Application Method	Backpack	Backpack
Mixing Procedure	Open	Open

[a] Subsets of Mixer/Loader/Applicator data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.
[b] Data quality for Airborne, Dermal Uncovered, Dermal Covered are all Grade A or B; Hand data are all Grade C. Data quality grades are defined in the text and in Versar (1992).

Figure 9-1. Summary of results from the PHED subset [a]

SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES
SCENARIO: Long pants, long sleeves, gloves

PATCH LOCATION	MICROGRAMS PER AVERAGE LB AI Mean	Coef of Var	Geo. Mean	Obs.
HEAD (ALL)	345.2564	194.899	91.4483	11
NECK.FRONT	178.6391	155.1078	38.2719	11
NECK.BACK	1163.209	108.1731	611.9794	11
UPPER ARMS	10116.4827	239.4633	257.2654	11
CHEST	275.4477	170.903	65.7564	11
BACK	8918.1809	167.9854	1044.0635	11
FOREARMS	153.593	184.2219	30.0425	11
THIGHS	597.2782	282.8189	49.147	9
LOWER LEGS	425.8878	230.6324	64.6874	9

Subset Name:
S20DERMAL.MLAP

[a] Subset criteria included actual and estimated head patches. Of the 11 head observations, all were actual.

Table 9-2. PHED data from dermal, hand, and inhalation subsets [a]

Exposure Category	Exposure (µg/lb AI handled)	Replicates in subset	Short-Term Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand) [c]	22,300	11 [d]	6	2
Hand (with gloves)	9.68	11	6	2
Inhalation	17.5	11	6	2

[a] Results from subsets of Mixer/Loader/Applicator data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.
[b] Multipliers are explained in the text and in Powell (2002).
[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (U.S. EPA, 1997).
[d] Median number of replicates was used in determining subset multipliers.

Table 9-3. Values Used in Exposure Calculations [a]

	Short-Term Exposure	Long-Term Exposure
Total Dermal (all PPE) [b]	6(2,650 + 9.68) = 16,000 µg/lb AI handled	2(2,650 + 9.68) = 5,320 µg/lb AI handled
Inhalation [c]	6(1.75) = 10.5 µg/lb AI handled	2(1.75) = 3.50 µg/lb AI handled

[a] Values from Table 9-2. Results rounded to three significant figures.
[b] Estimates adjusted for personal protective equipment (PPE): coveralls assumed to provide 90% protection (Thongsinthusak *et al*, 1991) to all but head, hands, and feet.
[c] 90% protection factor applied to inhalation exposure for use of respirator (NIOSH, 1987).

APPENDIX 10: SUBSET FROM PHED FOR MIXER/LOADER/APPLICATORS USING HIGH PRESSURE HANDWAND SPRAYERS

Table 10-1. Description of Pesticide Handlers Exposure Database (PHED) subsets [a]

		Actual characteristics of resulting

Parameter	Specifications used to generate subsets [a]	subsets
Data Quality Grades [b]	A,B,C	A,C
Liquid Type	Not specified	Microencapsulated
Application Method	High pressure hand wand	High Pressure Handwand, Greenhouse/Ornamental
Mixing Procedure	Open	All open

[a] Subsets of Mixer/Loader/Applicator data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.
[b] Data quality for Airborne, Dermal Uncovered, Dermal Covered are all Grade A; Hand data are all Grade C. Data quality grades are defined in the text and in Versar (1992).

Figure 10-1. Summary of results from the PHED dermal subset [a]

SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES

SCENARIO: Long pants, long sleeves, gloves

PATCH LOCATION	MICROGRAMS PER AVERAGE LB AI Mean	Coef of Var	Geo. Mean	Obs.
HEAD (ALL)	335.34	189.3598	108.1326	13
NECK.FRONT	684.7243	169.8879	240.7374	7
NECK.BACK	502.1311	169.8879	176.5408	7
UPPER ARMS	1000.3013	153.8867	353.808	13
CHEST	1220.2988	153.8867	431.6215	13
BACK	1220.2988	153.8867	431.6215	13
FOREARMS	415.9328	153.8867	147.1161	13
THIGHS	614.7471	125.9135	325.0308	7
LOWER LEGS	383.01	125.9135	202.5061	7

Subset Name:
S21DERMAL.MLAP

[a] Subset criteria included actual and estimated head patches. Of the 80 head observations, 10 were actual and 70 were estimated from nearby patches (Versar, 1992).

Table 10-2. PHED data from dermal, hand, and inhalation subsets [a]

Exposure Category	Exposure (µg/lb AI handled)	Replicates in subset	Short-Term Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand) [c]	6,580	13 [d]	5	2
Hand (with gloves)	339	13	5	2
Inhalation	151	13	5	2

[a] Results from subsets of Mixer/Loader/Applicator data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.
[b] Multipliers are explained in the text and in Powell (2002).
[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (U.S. EPA, 1997).
[d] Median number of replicates was used in determining subset multipliers.

Table 10-3. Values Used in Exposure Calculations [a]

	Short-Term Exposure	Long-Term Exposure
Total Dermal (all PPE) [b]	5(1,140 + 339) = 7,400 µg/lb AI handled	2(1,140 + 339) = 2,960 µg/lb AI handled
Inhalation [c]	5(15.1) = 75.5 µg/lb AI handled	2(15.1) = 30.2 µg/lb AI handled

[a] Values from Table 10-2. Results rounded to three significant figures.
[b] Estimates adjusted for personal protective equipment (PPE): coveralls assumed to provide 90% protection (Thongsinthusak *et al*, 1991) to all but head, hands, and feet.
[c] 90% protection factor applied to inhalation exposure for use of respirator (NIOSH, 1987).

APPENDIX 11: SUBSET FROM PHED FOR MIXER/LOADER/APPLICATORS USING LOW PRESSURE HANDWAND SPRAYER WITH LIQUID FORMULATIONS

Table 11-1. Description of Pesticide Handlers Exposure Database (PHED) subsets [a]

		Actual characteristics of

Parameter	Specifications used to generate subsets [a]	resulting subsets
Data Quality Grades [b]		
Airborne	A,B	A, B
Dermal and Hand	A, B, C	A, B, C
Liquid Type	Emulsifiable concentrate, aqueous suspension, microencapsulated, solution, or undiluted liquid	Solution or Microencapsulated
Application Method	Low Pressure Handwand	Low Pressure Handwand
Mixing Procedure	Not specified	All open

[a] Subsets of Mixer/Loader/Applicator data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.
[b] Data quality grades are defined in the text and in Versar (1992).

Figure 11-1. Summary of results from the PHED dermal subset [a]

SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES
SCENARIO: Long pants, long sleeves, gloves

PATCH LOCATION	MICROGRAMS PER AVERAGE LB AI Mean	Coef of Var	Geo. Mean	Obs.
HEAD (ALL)	658.5361	136.7049	290.5017	80
NECK.FRONT	137.9226	369.6483	18.9272	80
NECK.BACK	86.3274	429.9868	14.8349	79
UPPER ARMS	111.8313	232.934	32.6211	10
CHEST	235.1875	185.929	48.9756	10
BACK	163.797	202.4421	41.5723	10
FOREARMS	40.9585	267.6492	9.412	10
THIGHS	37.9878	115.1859	27.6737	9
LOWER LEGS	66.9309	164.3135	30.0241	9

Subset Name:
S22DERMAL.MLAP

[a] Subset criteria included actual and estimated head patches. Of the 80 head observations, 10 were actual and 70 were estimated from nearby patches (Versar, 1992).

Table 11-2. PHED data from dermal, hand, and inhalation subsets [a]

Exposure Category	Exposure (µg/lb AI handled)	Replicates in subset	Short-Term Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand) [c]	1,570	10 [d]	6	2
Hand (with gloves)	10.4	10	6	2
Inhalation	22.8	10	6	2

[a] Results from subsets of Mixer/Loader/Applicator data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.
[b] Multipliers are explained in the text and in Powell (2002).
[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (U.S. EPA, 1997).
[d] Median number of replicates was used in determining subset multipliers.

Table 11-3. Values Used in Exposure Calculations [a]

	Short-Term Exposure	Long-Term Exposure
Total Dermal (all PPE) [b]	6(777 + 10.4) = 4,720 µg/lb AI handled	2(777 + 10.4) = 1,570 µg/lb AI handled
Inhalation [c]	6(2.28) = 13.7 µg/lb AI handled	2(2.28) = 4.56 µg/lb AI handled

[a] Values from Table 11-2. Results rounded to three significant figures.
[b] Estimates adjusted for personal protective equipment (PPE): coveralls assumed to provide 90% protection (Thongsinthusak *et al*, 1991) to all but head, hands, and feet.
[c] 90% protection factor applied to inhalation exposure for use of respirator (NIOSH, 1987).

APPENDIX 12: SUBSET FROM PHED FOR MIXER/LOADER/APPLICATORS USING LOW PRESSURE HANDWAND WITH WETTABLE POWDER FORMULATIONS

Table 12-1. Description of Pesticide Handlers Exposure Database (PHED) subsets [a]

		Actual characteristics of resulting

Parameter	Specifications used to generate subsets [a]	subsets
Data Quality Grades [b]	A,B,C	A,C
Solid Type	Wettable powder	Wettable powder
Application Method	Low Pressure Handwand	Low Pressure Handwand
Mixing Procedure	Not specified	All open

[a] Subsets of Mixer/Loader/Applicator data in the Pesticide Handlers Exposure Database (PHED). Parameter descriptions are from screens displayed in the PHED program.
[b] Data quality for Airborne, Dermal Uncovered, Dermal Covered are all Grade C; Hand data are all Grade A. Data quality grades are defined in the text and in Versar (1992).

Figure 12-1. Summary of results from the PHED dermal subset [a]

SUMMARY STATISTICS FOR CALCULATED DERMAL EXPOSURES
SCENARIO: Long pants, long sleeves, gloves

PATCH LOCATION	MICROGRAMS PER AVERAGE LB AI Mean	Coef of Var	Geo. Mean	Obs.
HEAD (ALL)	2636.0019	179.0708	1267.5067	16
NECK.FRONT	756.6675	296.038	176.9167	16
NECK.BACK	151.0809	73.0526	109.8324	16
UPPER ARMS	494.7182	36.3833	463.0868	16
CHEST	700.3928	71.0002	603.0781	16
BACK	611.7981	38.4089	569.1622	16
FOREARMS	448.2142	146.8857	287.9792	16
THIGHS	5126.2967	165.785	2440.9362	16
LOWER LEGS	458.983	52.9223	410.828	16

Subset Name:

S23DERMAL.MLAP

[a] Subset criteria included actual and estimated head patches. Of the 16 head observations, all were actual.

Table 12-2. PHED data from dermal, hand, and inhalation subsets [a]

Exposure Category	Exposure (µg/lb AI handled)	Replicates in subset	Short-Term Multiplier [b]	Long-Term Multiplier [b]
Dermal (non-hand) [c]	11,600	16 [d]	5	1
Hand (with gloves)	3,430	15	5	1
Inhalation	1,040	16	5	1

[a] Results from subsets of Mixer/Loader/Applicator data in the Pesticide Handlers Exposure Database (PHED). Results rounded to three significant figures.
[b] Multipliers are explained in the text and in Powell (2002).
[c] Dermal total includes addition of default feet value of 0.52 x (value for lower legs); ratio of feet/lower leg surface area (U.S. EPA, 1997).
[d] Median number of replicates was used in determining subset multipliers.

Table 12-3. Values Used in Exposure Calculations [a]

	Short-Term Exposure	Long-Term Exposure
Total Dermal (all PPE) [b]	5(3,730 + 3,430) = 35,800 µg/lb AI handled	1(3,730 + 3,430) = 7,160 µg/lb AI handled
Inhalation [c]	5(104) = 520 µg/lb AI handled	1(104) = 104 µg/lb AI handled

[a] Values from Table 12-2. Results rounded to three significant figures.
[b] Estimates adjusted for personal protective equipment (PPE): coveralls assumed to provide 90% protection (Thongsinthusak *et al*, 1991) to all but head, hands, and feet.
[c] 90% protection factor applied to inhalation exposure for use of respirator (NIOSH, 1987).

APPENDIX 13: CALCULATION OF PARAMETERS USED IN ESTIMATING DERMAL EXPOSURE TO WORKERS DIPPING NURSERY STOCK

1. K_p is the skin permeability coefficient, calculated as follows (U.S. EPA, 2004a):

$$\log K_p = -2.80 + 0.66 \log K_{ow} - 0.0056\ MW$$

With MW of 406.96 and Log K_{ow} of 4.74, the K_p is 0.0112 cm/hr for endosulfan.

2. B is the dimensionless ratio of two permeability coefficients, one for the stratum corneum (SC) and one for the epidermis (EPI). However, as explained by Bunge and Cleek (1995), the permeability coefficient for the epidermis is exceedingly difficult to determine: "Although experimental protocols exist for removing the EPI leaving an intact SC, techniques for removing the SC without damaging the EPI do not exist." Because the permeability of the epidermis is almost never known, Bunge and Cleek (1995) proposed four methods of estimating B without knowing the epidermal permeability, based on empirical data and theory. B is estimated from Equation A.1 in U.S. EPA (2004a). Equation A.1 is based on Method 4 in Bunge and Cleek (1995):

$$B = K_p[(MW)^{0.5}/(2.6\ \text{cm/hr})]$$

where K_p is the estimated steady-state dermal permeability coefficient in water, calculated as above.

For endosulfan,

$$B = (0.0112)[(406.96)^{0.5}/(2.6)] = 0.0870.$$

3. τ is the lag time per event (hours). The lag time is how long it takes for a chemical to cross the skin, including both the SC and EPI (Bunge *et al*., 1995). τ is calculated as follows (U.S. EPA, 2004a):

$$\tau = 0.105 \times 10^{(0.0056\ MW)}$$

For endosulfan, MW = 406.96. Thus,

$$\tau = 0.105 \times 10^{(0.0056 * 406.96)} = 0.105 \times 10^{(2.279)} = 0.105\ (190) = 19.9 \text{ hours}$$

4. The equation for dermal exposure per event DA_{event} in RAGS-E is as follows (modified from Equation 3.3 in U.S. EPA (2004a), surface area term added to get result in mg/event rather than mg/cm2):

$$DA_{event} = FA * K_p * SA * C_w * (0.001\text{L/cm}^3) * [t/(1+B) + 2\tau((1+3B+3B^2)/(1+B)^2)]$$

Appendix 13, Continued...

where

DA_{event} is the absorbed dose per event (mg per event);
FA is the fraction absorbed water (dimensionless, default = 1);
SA (cm^2) is surface area of exposed skin;
C_w is the concentration of the pesticide in water (multiply by the appropriate protection factor);
t is the event duration (hours); and
other parameters are as defined above.

5. Absorbed daily dose is calculated by dividing the DA_{event} by the body weight (BW).

Results of above calculations are summarized in Table 13-1.

Table 13-1. Dermal Endosulfan Exposures Estimated with Equations from RAGS-E [a]

Parameter	Value
K_p (cm/hr) [b]	0.0112
τ (hours) [c]	19.9
B [d]	0.0870
Hands	
DA_{event} (mg per day) [e]	319
ADD (mg/kg/day) [f]	4.56
Non-Hand Dermal	
DA_{event} (mg per day) [g]	2,580
Dermal ADD (mg/kg/day) [h]	36.87
Total Dermal	
Total Dermal ADD (mg/kg/day) [i]	41.4

[a] C_w = 6,000 mg/L for endosulfan (concentration in solution prepared according to directions on Thiodan® 3EC product label). C_w multiplied by 0.1 for gloves and coveralls over one layer of clothing, default protection factor of 90% (Thongsinthusak *et al.*, 1991; Aprea *et al.*, 1994).
[b] Skin permeability coefficient (K_p) calculated from Equation 3.8 in U.S. EPA (2004a).
[c] Lag time to reach steady-state (τ) calculated from Equation A.4 in U.S. EPA (2004a). The lag time is how long it takes for a chemical to cross all skin layers (Bunge *et al.*, 1995).
[d] Calculated from Equation A.1 in U.S. EPA (2004a), based on Method 4 in Bunge and Cleek (1995).
[e] Estimated hand exposure per day. Calculated from Equation 3.3 in U.S. EPA (2004a), SA = 904 cm^2 (surface area both hands; combined male and female medians from EPA, 1997). ET = 8 hours.
[f] ADD is absorbed daily dose. DA_{event} divided by 70 kg default body weight to obtain dermal dose (Thongsinthusak *et al.*, 1993).
[g] Estimated dermal exposure per day. Calculated from Equation 3.3 in U.S. EPA (2004a), SA = 7,306 cm^2 (surface area of chest/stomach, forearms, front of thighs and lower legs; combined male and female medians from EPA, 1997). ET = 8 hours.
[h] Dermal ADD is absorbed daily dose. AD_{Derm} divided by 70 kg default body weight to obtain dermal dose (Thongsinthusak *et al.*, 1993).
[i] Total Dermal ADD is the sum of ADD for hands and Dermal ADD.

APPENDIX 14: CALCULATION OF PARAMETERS USED IN ESTIMATING INHALATION EXPOSURE TO WORKERS DIPPING NURSERY STOCK

SWIMODEL estimates ambient vapor concentration of a chemical from its air-water partitioning using its unitless Henry's Law constant, which is calculated as follows (U.S. EPA, 2003):

$$C_{vp} = H' * C_w * (1{,}000 \text{ L/m}^3)$$

where

C_{vp} (μg/m^3) is the concentration of the pesticide in air;
H' is the unitless Henry's Law constant; and
C_w is the concentration of chemical in water (μg/L).

The unitless Henry's Law constant is calculated based on the Henry's Law constant in units of atm-m^3/mole using the following equation:

$$H' = H/(R * T)$$

where
H' is the unitless Henry's Law constant;
H is the aqueous Henry's Law constant (atm-m^3/mole);
R is the gas constant (8.19 x 10^{-5} atm-m^3/mole-K); and
T is the ambient air temperature (degrees Kelvin, or 273 added to degrees Celsius).

SWIMODEL calculates the potential dose rate in mg per event ($AD_{Inhalation}$) as:

$$AD_{Inhalation} = Cvp * ET * IR * (1 \text{ mg}/1{,}000\ \mu\text{g})$$

where
C_{vp} (μg/m^3) is the concentration of the pesticide in air;
ET (hrs/event) is exposure time; and
IR (m^3/hr) is inhalation rate.

However, endosulfan products contain additives to increase water solubility. Because of this, the vapor concentration calculated from the SWIMODEL equation is quite high, perhaps above concentrations that could actually occur. To check this, the equation used to estimate vapor pressure by the gas saturation method (U.S. EPA, 1996) can be re-arranged to provide an estimate of saturated vapor concentration based on reported vapor pressure. The equation is given below.

$$C_{sat} = [(VP/760) * MW * (1{,}000 \text{ mg/g})(1{,}000 \text{ L/m}^3)]/R*T$$

where
C_{sat} (μg/m^3) is the saturated concentration of the pesticide in air;
MW is the molecular weight;
R is the gas constant (8.19 x 10^{-5} atm-m^3/mole-K); and
T is the ambient air temperature (degrees Kelvin, or 273 added to degrees Celsius).

Appendix 14, Continued...

The estimated C_{sat} is given in Table 14-1. This value is considerably lower than the estimated C_{vp}, suggesting that C_{vp} is unrealistically high. Therefore, C_{sat} was used in calculating inhalation exposure.

A default value of 20 m^3/day was used for IR (Andrews and Patterson, 2000); this value assumes moderate to heavy activity during an 8-hour workday. Because IR is given for the workday rather than on an hourly basis, ET is set to 1 day in the exposure calculation. This result is multiplied by 0.1 for use of a respirator (NIOSH, 1987). The inhalation contribution to the ADD is calculated by dividing the inhalation exposure estimate by the default body weight of 70 kg (Thongsinthusak *et al*., 1993). Exposure estimates are given in Table 14-1.

Table 14-1. Inhalation Endosulfan Exposure Estimate Based on SWIMODEL Equations [a]

Parameter	Value
H' [b]	0.00175
C_{vp} [c]	1.05×10^7
C_{sat} [d]	1,682
$AD_{Inhalation}$ (mg per day) [e]	3.36
Inhalation ADD (mg/kg/day) [f]	0.048

[a] C_w = 6,000 mg AI/L for endosulfan (concentration in solution prepared according to directions on Thiodan® 3EC product label).
[b] Unitless Henry's Law constant. See text for equation.
[c] Calculated concentration of pesticide in air. See text for equation.
[d] Saturated vapor concentration. See text for equation.
[e] Estimated inhalation exposure per day. See text for equation. C_{sat} used for C_{vp}, IR = 20 m^3/day, ET = 1 day. Exposure was multiplied by 0.1 for use of a respirator (NIOSH, 1987).
[f] ADD is absorbed daily dose. To calculate, $AD_{inhalation}$ divided by 70 kg default body weight to obtain dose (Thongsinthusak *et al*., 1993).

APPENDIX 15: EFFECTS OF MITIGATION MEASURES PROPOSED IN ENDOSULFAN RED ON EXPOSURE ESTIMATES

Exposure estimates in this exposure assessment document (EAD) were based on labeling that is currently in effect. U.S. EPA released the Reregistration Eligibility Decision (RED) for endosulfan in November 2002 (U.S. EPA, 2002a). Many of the mitigation measures proposed in the RED would change handler and reentry exposure estimates. These are briefly summarized in this appendix, and revised exposure estimates are given for future reference.

All uses of endosulfan would be deleted for the following crops: succulent beans, succulent peas, spinach, grapes, and pecans. Endosulfan use on tobacco would be restricted to six eastern states, and use would not be allowed in states such as California. Uses of wettable powder (WP) products would be canceled in several crops, such as tomatoes, sweet corn, and cotton. Aerial applications of WP products would not be allowed in several other crops, including tree fruits and nuts, which have the highest application rates; aerial applicator exposure estimates would be affected. All WP products would be in water soluble packaging, which would eliminate the highest M/L exposure estimates.

A few changes in application rates were proposed for specific crops or use sites in U.S. EPA (2002a). Many of these would not apply in California, either because products are not registered in California or because endosulfan products registered in California already list the proposed maximum application rates. Proposed application rate changes that would affect worker exposure estimates include a decrease in rates allowed with high pressure handwand sprayers (to 0.005 lbs AI/gallon) and a decrease in the maximum application rate allowed on strawberries, from 2.0 lbs AI/acre to 1.0 lb AI/acre. This would decrease exposure estimates for strawberry harvesters.

Closed M/L systems would be required for aerial applications of emulsifiable concentrate (EC) products on all crops in which WP aerial uses were canceled, and to most crops in which WP uses were canceled completely. Because closed M/L systems are required under California law, this proposed measure would not affect exposure estimates. Closed cab would be required for airblast applications to tree crops, which would result in lower estimates. Since the release of U.S. EPA (2002a), the Agricultural Handlers Exposure Task Force has submitted an exposure monitoring study for airblast applicators driving open-cab tractors and wearing chemical-resistant headgear (Smith, 2005). This study resulted in lower estimates for open-cab airblast applicators than estimates based on PHED, but not as low as closed-cab airblast applicator exposure estimates.

Changes in handler exposure estimates due to proposed mitigation measures are summarized in Table 15-1. No changes are anticipated in estimates for handlers involved in groundboom applications, backpack applications, low pressure handwand applications, and nursery stock dips with endosulfan, and these scenarios are not included in Table 15-1.

Table 15-1. Estimates of Pesticide Handler Exposure to Endosulfan Based on Mitigation Measures Proposed in the Reregistration Eligibility Decision [a]

Scenario [b]	STADD [c] (mg/kg/day)		SADD [c] (mg/kg/day)		AADD [c] (mg/kg/day)		LADD [c] (mg/kg/day)	
	Old	New	Old	New	Old	New	Old	New
Aerial [d]								
M/L EC	0.225	0.225	0.034	0.034	0.011	0.011	0.006	0.006
M/L WSP	0.185	**0.074**	0.044	**0.030**	0.015	**0.010**	0.008	**0.005**
Applicator	0.790	0.790	0.158	0.158	0.053	0.053	0.028	0.028
Flagger	0.373	0.373	0.057	0.057	0.019	0.019	0.010	0.010
High-Acre Aerial [d]								
M/L EC	0.463	0.463	0.116	0.116	0.029	0.029	0.015	0.015
M/L WSP	0.381	**0.254**	0.152	**0.101**	0.038	**0.025**	0.020	**0.014**
Applicator	1.63	1.63	0.542	0.542	0.135	0.135	0.072	0.072
Airblast [e]								
M/L EC	0.026	0.026	0.006	0.006	0.001	0.001	0.0006	0.0006
M/L WSP	0.021	0.021	0.008	0.008	0.001	0.001	0.0008	0.0008
Applicator	0.188	**0.052**	0.048	**0.013**	0.008	**0.002**	0.004	**0.001**
HPHW [f]								
M/L/A EC	0.511	**0.256**	0.153	**0.077**	0.026	**0.013**	0.014	**0.007**

[a] Mitigation measures proposed in U.S. EPA (2002a).
[b] Abbreviations: EC = emulsifiable concentrate. M/L = mixer/loader. M/L/A = mixer/loader/applicator. WP = wettable powder. WSP = water soluble packaging containing wettable powder. Because WP would be in WSP, M/L and M/L/A scenarios involving WP were omitted (only EC and WSP were included).
[c] Combined dermal and inhalation exposure estimates. "Old" estimates are based on existing product labels; calculations are shown in Tables 17 - 20. "New" estimates incorporate proposed mitigation measures; changed estimates (affected by proposed mitigation) are shown in bold, while unchanged estimates are not. Abbreviations: STADD = Short-Term Absorbed Daily Dosage. SADD = Seasonal Average Daily Dosage. AADD = Annual Average Daily Dosage. LADD = Lifetime Average Daily Dosage.
[d] "New" M/L WSP estimates assumed a maximum rate on vegetable and field crops of 1.0 lb AI/acre, as aerial applications of WP are to be cancelled on pome fruit, stone fruits, citrus, blueberries, strawberries, collard greens (seed), kale (seed), mustard greens (seed), radish (seed), turnip (seed), rutabaga (seed), broccoli, (seed), cauliflower (seed), kohlrabi (seed), cabbage (seed), filberts, walnuts, almonds, and macadamia nuts (U.S. EPA, 2002a).
[e] "New" airblast applicator exposure estimates assumed use of a closed cab, as proposed in U.S. EPA (2002a).
[f] "New" HPHW M/L/A exposure estimates assumed maximum application rate of 0.005 lbs AI/gallon, as proposed in U.S. EPA (2002a).

To mitigate reentry worker risk, U.S. EPA (2002a) proposed lengthening the baseline restricted entry interval (REI) from 24 hours to 48 hours. In California, current regulations already require a baseline REI of 48 hours (Title 3 Code of California Regulations, Section 6772), and reentry exposure estimates would not be affected by this proposed mitigation measure. However, longer REIs were proposed for some crops; these are listed in Table 15-2.

Table 15-2. Formulation-Specific Restricted Entry Intervals (REIs) Proposed in Endosulfan Reregistration Eligibility Decision [a]

	REI (days)	
Crop	**WP**	**EC**
Melons, cucurbits	3	2
Lettuce, celery, pome fruit, stone fruit, citrus, collard greens, kale, mustard greens, radish, turnip, rutabaga, ornamental trees and shrubs	4	2
Collard greens (seed), kale (seed), mustard greens (seed), radish (seed), turnip (seed), rutabaga (seed)	5	2
Broccoli, cauliflower, kohlrabi, cabbage, Brussels sprouts	9	4
Broccoli (seed), cabbage (seed), cauliflower (seed), kohlrabi (seed)	12	7
Sweet potato	NA [b]	3
Sweet corn	NA	17

[a] Proposed in U.S. EPA (2002). California regulations require a minimum REI of 2 days (Title 3 Code of California Regulations, Section 6772). WP = wettable powder products. EC = emulsifiable concentrate products.

[b] NA: not applicable. Use of WP endosulfan products would not longer be allowed.

U.S. EPA (2002a) used formulation-specific DFR curves in estimating exposure, based on data later published by Whitmyre *et al.* (2004). Thus, many proposed REI changes were formulation-specific, as shown in Table 15-2. Table 15-3 shows revised exposure estimates for reentry workers based on changes in application rate (for strawberry harvesters) and REI shown in Table 15-3. As DFR data used in exposure estimates in this EAD followed applications of WP formulations (Table 10), revised exposure estimates based on the proposed WP REI are given in Table 15-3.

1 **Table 15-3. Reentry Worker Exposure Estimates to Endosulfan Based on Mitigation**
2 **Measures Proposed in the Reregistration Eligibility Decision [a]**

Exposure scenario	STADD [b] (mg/kg/day)	SADD [c] (mg/kg/day)	AADD [d] (mg/kg/day)	LADD [e] (mg/kg/day)
Almond, Hand Harvesting [f]	**0.012**	NA	NA	NA
Almond, Thinning [f]	**0.007**	NA	NA	NA
Broccoli, Hand Harvesting [g]	**0.019**	**0.006**	**0.0009**	**0.0005**
Broccoli, Scouting [g]	**0.015**	**0.005**	**0.0011**	**0.0006**
Citrus, Scouting [h]	**0.012**	NA	NA	NA
Sweet Corn, Hand Harvesting [i]	**0.028**	**0.020**	**0.002**	**0.001**
Cotton, Scouting [j]	0.082	0.009	0.001	0.0008
Cucumber, Hand Harvesting [k]	**0.039**	0.007	0.001	0.0007
Grape, Cane Turning [l]	**NA**	**NA**	**NA**	**NA**
Lettuce, Scouting [m]	**0.018**	**0.002**	**0.001**	**0.0005**
Cut Flowers, Hand Harvesting [n]	**0.121**	NA	NA	NA
Ornamental Plants, Hand Harvesting [n]	**0.007**	NA	NA	NA
Peach, Thinning [o]	**0.037**	**0.015**	**0.003**	**0.001**
Potato, Scouting [j]	0.055	0.004	0.002	0.001
Strawberry, Hand Harvesting [p]	**0.034**	NA	NA	NA
Tomato, Hand Harvesting [j]	0.17	0.009	0.003	0.002

[a] Mitigation measures proposed in U.S. EPA (2002a). Changed estimates (affected by proposed mitigation) are shown in bold, while unchanged estimates are not. See Tables 21 and 22 for exposure estimates based on current product labels; Table 21 also contains transfer coefficients used in exposure estimates.
[b] Short-Term Absorbed Daily Dosage (STADD) is an upper-bound estimate of exposure.
[c] Seasonal Average Daily Dosage is a mean estimate of absorbed dose, calculated as described in text.
[d] Annual Average Daily Dosage = ADD x (annual use months per year)/(12 months in a year).
[e] Lifetime Average Daily Dosage = AADD x (40 years of work in a lifetime)/(75 years in a lifetime).
[f] Change in maximum application rate to 2.0 lbs AI/acre. DFR for STADD, hand harvesting = 0.27 $\mu g/cm^2$. DFR for STADD, thinning = 0.09 $\mu g/cm^2$.
[g] Change in REI to 9 days. DFR for STADD = 0.07 $\mu g/cm^2$. DFR for SADD = 0.021 $\mu g/cm^2$.
[h] Change in REI to 4 days. DFR for STADD = 0.23 $\mu g/cm^2$.
[i] Change in REI to 17 days. DFR for STADD = 0.031 $\mu g/cm^2$. DFR for SADD = 0.022 $\mu g/cm^2$.
[j] No change in exposure estimates for this scenario.
[k] Change in REI to 3 days. DFR for STADD = 0.29 $\mu g/cm^2$. Other estimates unchanged.
[l] Endosulfan use on grapes would be discontinued.
[m] Change in REI to 4 days. DFR for STADD = 0.22 $\mu g/cm^2$. DFR for SADD = 0.029 $\mu g/cm^2$.
[n] Change in REI to 4 days. DFR for STADD = 0.32 $\mu g/cm^2$.
[o] Change in REI to 4 days. DFR for STADD = 0.23 $\mu g/cm^2$. DFR for SADD = 0.093 $\mu g/cm^2$.
[p] Change in maximum application rate to 1.0 lbs AI/acre. DFR for STADD = 0.42 $\mu g/cm^2$.

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